





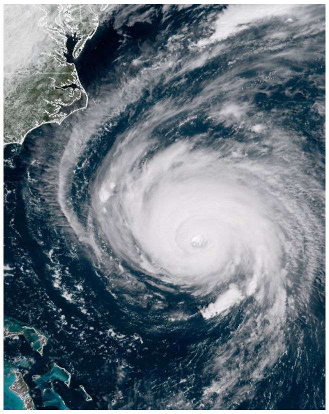


Global Building Resilience Guidelines

Guidelines for Resilient Buildings to Extreme Weather

November 2022

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PART 1: PREAMBLE

The goal of the Global Resiliency Dialogue[1] is to identify solutions to help address the global challenge posed by the impact of increasingly frequent and extreme weather events and hazard risks (including heatwaves) on building occupants and buildings.[2]

The Global Resiliency Dialogue has two overarching objectives:

- to understand and disseminate the latest in climate science and building practices to help inform the ongoing development of building codes that improve the resilience of buildings and structures around the world.
- to enhance the utility of current building codes to respond proportionately to rapidly changing and predicted extreme weather events such as flooding, storms, cyclones/hurricanes, wildfires/bushfires and heatwaves.

The Global Resiliency Dialogue recognizes that building codes used today around the world may not provide the same level of safety and resilience for future extreme weather events as they have in the past.

The Global Resiliency Dialogue believes it is desirable and increasingly necessary for codes and standards to respond to the latest research and data from the perspective of both building science and climate/environment science if they are to maintain not only an expected level of safety and amenity, but also an appropriate level of resilience. By working together, participating organizations can pool their collective resources, experience and knowledge to create guidelines and research that will be of both national value and global benefit.

Ahead of the development of these Global Building Resilience Guidelines (the Guidelines), the Global Resiliency Dialogue worked collectively to engage with local interests and participate in coordinated surveys to source a body of information as input to the work.

The first report developed through the collective engagement of this partnership, investigated how climate-based risks are currently addressed in national building codes and standards. In addition to input from the Australian Building Codes Board (ABCB), the National Research Council of Canada (NRC), the New Zealand Ministry of Business, Innovation and Employment (MBIE), and the International Code Council (ICC), responses to the first survey were received by counterpart organizations in Europe (Germany, the Netherlands and Norway) and Asia (Japan). This broadening of international interest offered a more diverse snapshot of the status and approaches to integrating climate science in existing building codes around the world. A copy of the report, released in January 2021, is available here.

The second phase of the research consisted of an international survey distributed to selected stakeholders based in Canada, Australia, New Zealand and the United States. The survey sought input from climate scientists, design professionals, government bodies, standards developers, key industry bodies, emergency management and professional bodies on a range of opportunities and challenges to better address resilience needs in the built environment.

The purpose of the second survey was to better understand and determine what possibilities and different types of climate modelling exists or are under development to enable building codes to be more predictive and forward-looking in anticipation of extreme weather events and hazards that are likely to impact the built environment. The second report was released to coincide with the 26th United Nations Climate Change Conference of the Parties (COP26) in November 2021, a copy of which can be found here.

The results from both reports have contributed significantly to the development of the Guidelines. This Global Resiliency Dialogue product is intended to bring together the collective knowledge, frameworks and principles from code development bodies around the world. Continued sharing of knowledge will help develop contemporary standards to anticipate and respond to the challenges future climate presents to not only the occupants of buildings, but the resilience of communities.

While the focus of building codes is on future buildings, the challenges from climate change will affect all buildings. With that in mind, the Guidelines also consider the need for the upgrade of existing buildings, maintenance and compliance processes for all buildings, even though these fall outside the typical scope of most code development bodies.

[1] The Global Resiliency Dialogue is a collaborative of building code development and research organizations, along with interested government and non-government stakeholders from Canada, Australia, New Zealand and the United States who came together in late 2019 to collaborate on addressing the challenge of integrating climate science into building codes to enhance the resilience of buildings to future weather-related hazard events.

[2] Note that infrastructure, some of which is critical to the function of buildings and can equally be impacted by the effects of natural hazard events, is not included within the scope of the Guidelines as it will often sit outside the remit of building codes and building code regulators in the international community.

1.1 PROBLEM STATEMENT

Buildings being constructed today face in their service life the prospect of experiencing different and potentially more extreme weather than in the past, and possibly in geographic regions where such natural phenomena have not occurred before or with such intensity.

Contemporary building codes typically contain provisions and reference technical standards for design and construction to take account of most weather-related natural hazards, however, these are primarily based on data and experience from past events. Whereas in a non-stationary climate the problem relates to future conditions, which can be characterized based on scientific analysis of current trends and predicted events using sophisticated scenario modelling.

The problem extends to incorporate going beyond the recognized primary purpose of building codes, being public health and safety, to enabling buildings to continue to perform primary functions of shelter and re-occupation, even if rudimentary. To consider this further, it is a pre-requisite to provide a scope for what climate resilience means in the context of buildings, which is explored later.

The world's atmosphere is warming because of increased concentrations of greenhouse gas (GHG) emissions. This will continue to affect the earth's climate and has already resulted in an increase in the severity and incidence of weather-related natural hazards, as well as their geographic distribution.

Principal amongst these are extreme wind, extreme precipitation (resulting in severe flooding), wildfire/bushfire, extreme temperatures and extreme drought, all of which have the potential to impact the health and well-being of people and communities, and impose significant economic loss.

As far as this relates to the role of building codes and standards, the effects of climate change are already being experienced in the form of extreme weather events, with resultant loss of life, injury, community dislocation, property loss and damage, business disruption and both individual and societal financial impacts. Irrespective of the efforts to mitigate the causes of global warming, these conditions will continue for some time into the future given the accumulation of GHGs in the atmosphere.

1.2 PRINCIPLES

These Global Building Resilience Guidelines are intended to inform and encourage the development of building codes that incorporate future-focused climate resilience. The Guidelines are relevant for all building code and standards writing bodies. The Guidelines are organized around principles that provide a basis for advancing building resilience through building codes.

1. ***Urgency***
   The need to respond to the associated impacts of climate change and extreme weather events on buildings and building occupants is more urgent than ever.

2. ***Clarity of objectives***
   Building resilience requires attention to the changing climatic conditions buildings will face over their lifecycle and impacts on their expected operation following an extreme weather event. The importance of building codes focusing on occupant health and safety remains.

3. ***Robust climate science***
   Building code development will benefit from an evidence base that utilizes official climate forecasts in the local jurisdiction or models based on peer-reviewed scientific research and ideally provide a demonstration of various future state possibilities.

4. ***Risk clarity***
   Risk informed thinking and decision making is important in providing support for design decisions to balance cost, energy performance, greenhouse gas emissions and resilience, where changing risks can be balanced against certainty of performance for building development and maintenance.

5. ***Forward-looking***
   A baseline assessment of current technical construction standards, where they exist, enables a comparison to be made with modelling and scenarios for future climate to help determine if they remain adequate or if new ones need to be developed.

6. ***Durability***
   Understanding building design life is important not only to assist in determining minimum necessary technical construction standards, but to also calibrate the technical design requirements. This will help improve the resilience of buildings with a benchmark of durability that avoids unnecessarily harsh requirements and therefore costs.

7. ***Holistic approach***
   Building codes can contribute to improving building resilience as part of a broad suite of regulatory and non-regulatory measures. In some cases this will be inter-dependent and take account of multi-hazard weather related events.

8. ***Affordability***
   Building codes and standards consider, where possible, a regulatory principle of setting minimum requirements necessary to achieve the level of desired performance, while doing so cost effectively. This should also achieve the objective of improved building resilience, throughout the design life of a building, to the effects of weather-related natural hazard events under a range of future scenarios.

9. ***Existing buildings***
   Identify strategies to encourage existing building owners to bring their buildings up to a higher standard of resilience for the types of future weather-related natural hazards they may experience based on their location and climate projections.

10. ***Building maintenance***
    Encourage property owners to engage in the need for planned periodic and specified maintenance of their buildings and promote essential resilience features embedded within buildings to ensure their ongoing performance.

11. ***Compliance***
    Effective regulatory systems will incorporate appropriate resources to properly enforce the building codes and standards, as well as promote an ethic of compliance.

12. ***Implementation***
    Complement any regulatory measures to improve compliance and support technical solutions with a wide range of education and practitioner capacity building tools.

13. ***Monitor and evaluate***
    Routinely monitor the need to maintain the currency of building codes and standards in response to updated climate science and projections.

14. ***Engagement***
    Employ a clear and uncomplicated communication strategy that embraces and simplifies risk-based information; uses a common, credible and consistent set of evidence; and caters to the many and varied views of those with an interest in this subject.

15. ***Emissions reduction***
    Building code development can make an important contribution to mitigating the causes of climate change with subsequent long-term benefits for building resilience.

1.3 THE NEED FOR BUILDINGS TO BE MORE RESILIENT

Contemporary building codes typically make provisions for natural hazard events, including those generated by climate, except for extreme temperatures, which has only recently become more apparent with the impacts of heat stress. As noted in the problem statement, these provisions, as is the case with other hazards covered by building regulation (such as fire and structural failure), are usually based on minimum performance levels that are typically informed by historic data generated by past events. This information is then in turn used to determine appropriate design criteria for the primary purpose of safeguarding occupant health and safety, not protecting the building itself.

In the context of a changing climate and the prospect of more severe weather-related events occurring in previously unaffected geographic regions, the notion of what represents the baseline function of a building arises. Has a building served its purpose if it protects life, but is unusable following a damaging extreme weather-related event?

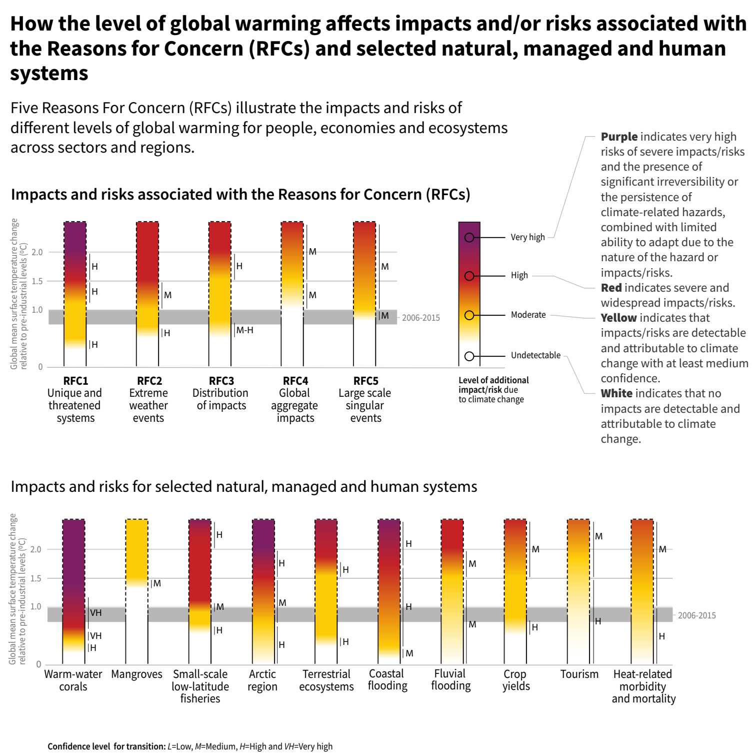
Mapping the probable change in climate by region and how this will impact a range of natural hazard events at a more granular level also needs to be considered when looking to address the performance of a building through its typical lifecycle of between 50 and 70 years.[3] Minimum technical construction standards will be more effective if they are developed to consider various weather-related events a building may experience over its lifetime.

This approach represents an important change to the development of natural hazard technical construction standards and building code provisions. This is because they would be designed on a predictive scientific evidence base to anticipate the types of events buildings are potentially going to experience, their required performance to protect the occupants and serve a basic level of amenity following an event. This can all still occur within the frame of minimum performance if it is accepted this remains the objective of such provisions.

The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) ahead of COP26 in November 2021,[4] outlines how different regions are already experiencing significant changes to their climate because of global warming, including more extreme and severe events occurring over longer durations and, in many cases, in areas that have not previously experienced them. The impacts of these climate hazard events will also be experienced differently based on geography and resource availability, urban versus rural locations and the socio-economic means of communities.

Figure 1 produced by the IPCC summarizes the key impacts and risks across sectors and regions that are described as reasons for concerns (RFCs) and illustrates the implications of global warming for people, economies and ecosystems.[5] Even RFC2 at 1.5 degrees Celsius, which is frequently the target temperature increase referred to by experts as the baseline target below which the world needs to remain to avoid increasing catastrophic events, points to severe and widespread impacts, including heat related morbidity and mortality, which is already the single greatest cause of loss of life through extreme weather events.

Figure 1



[3] It is important to note the impacts will be experienced differently globally for similar events due to broad wealth disparities between countries and therefore both the standard of construction and the capacity to recover. A typical example would be an extreme wind and rain event impacting an informal settlement in an emerging economy versus that of an established city in a developed economy.

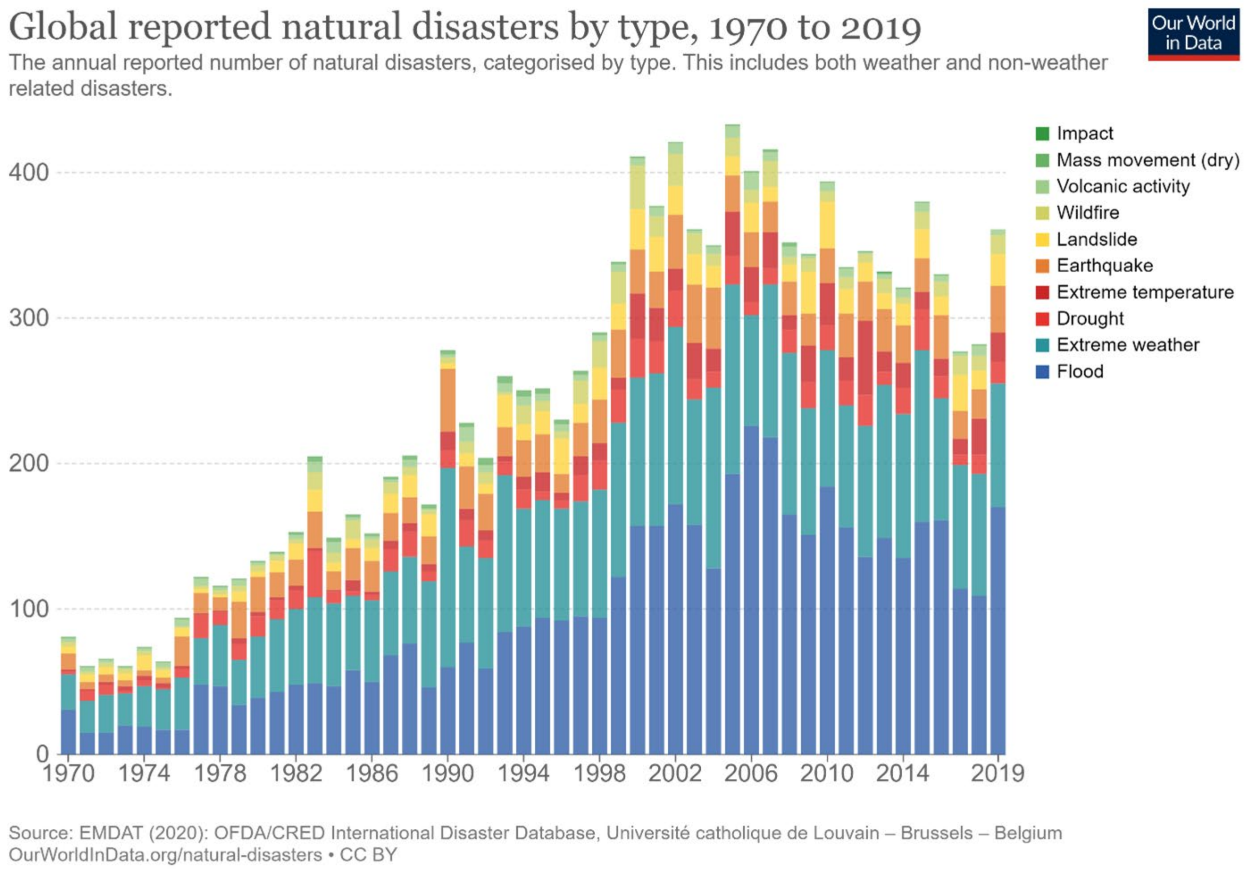
[4] Arias, P.A., N. Bellouin, E. Coppola, R.G., et. al. 2021.

[5] Figure SPM.2 from IPCC, 2018: Summary for Policymakers

The impacts of climate change on the built environment will not reside solely with risk to public health and safety. The International Finance Corporation (IFC) estimates that between 2000 and 2019, over 7,000 weather-related natural hazard events have affected 4.03 billion people and claimed 1.23 million lives, causing $2.97 trillion in economic losses. This is an increase from around 4,000 events causing $1.63 trillion losses between the previous 19 year period (1980-1999).[6]

Figure 2 highlights that weather-related disasters have increased in recent decades. Most notable in the context of these guidelines are increases in flooding, extreme weather, extreme temperature and wildfire.[7]

Figure 2



The economic losses from extreme weather events are experienced in many ways, including:

- loss of agricultural output leading to food shortages;
- replacement of infrastructure during which power supply and water contamination are often immediate issues to contend with;
- disruption to businesses potentially through property damage or access to supplies and;
- the replacement/repair of buildings.

The last of these impacts is often felt most personally as it affects access to shelter, the loss of possessions, loss of business function and often an inability to rebuild because of either under-insurance or a complete lack of insurance.

Globally reported disasters between 1970 and 2019, and urbanization of communities, have increased significantly. Urbanization trends signal higher exposure to natural hazards due to greater concentration of people and assets in urban areas. Globally, approximately 50% of the population lives in urban areas. By 2050, this number is projected to increase by 2.5 billion, to 68% of the total population, with 90% of urban expansion taking place in developing countries as informal and unplanned settlements. This growth is surging the demand for buildings and infrastructure in urban areas, many of which are in high-risk locations.[8] The economic losses of the last decade associated with natural hazard weather events increased by almost one trillion U.S. dollars from the previous decade, as illustrated in *Figure 3*.[9]

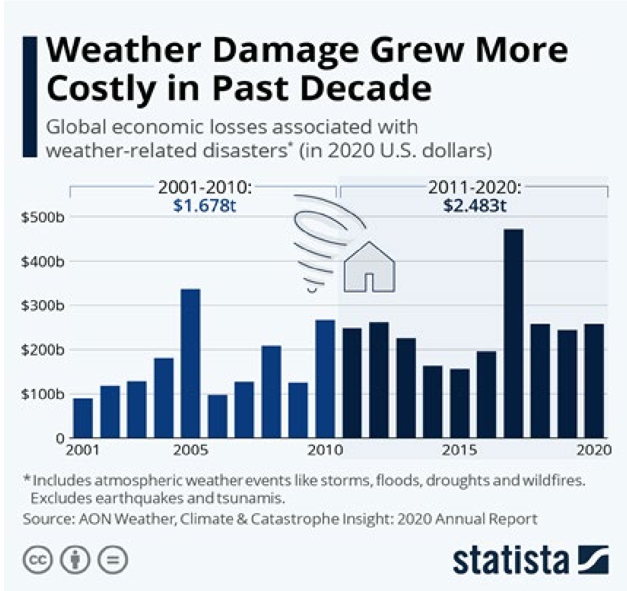
[6] International Finance Corporation. 2021.

[7] Ritchie, H. and Roser, M. 2014.

[8] International Finance Corporation. 2021.

[9] Buchholz, K. 2021.

Figure 3



According to the IFC, while more assets are being built in high-risk areas, most are not financially protected. The insurance sector traditionally only covers about one-third of losses caused by disasters on average, with the rest being shouldered by governments, businesses or individuals. This disposition is graphically illustrated in *Figure 4*, which displays by geographic region over the past decade, uninsured and insured losses from weather-related catastrophes in US dollars.[10]

Figure 4

Source: 2020_financial_report_swissre

The U.S. National Institute of Building Sciences (NIBS) estimates that adopting the latest building code requirements (in the United States) for new buildings saves 11 USD per 1 USD invested and going beyond the code saves a further 4 USD per 1 USD invested.[11] As stated by the IFC and recognized by the World Bank in its "Urban Development: Overview," investing in resilience makes business sense.[12]

It follows that enhancing the resilience of buildings to natural hazards impacted by climate change will not only save lives, but also mitigate economic losses, which are increasingly being borne by governments and individuals, particularly in developed economies. In emerging economies, the risk profile is different, with the prospect of being locked into vicious cycles of repeating recovery and reconstruction costs, which often perpetuate economic instability and deepen poverty.[13]

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[10] Swiss Re. 2020.

[11] Multi-Hazard Mitigation Council. 2019.

[12] International Finance Corporation. 2021.

[13] ibid.

1.4 TYPES OF NATURAL HAZARDS

There are many natural hazards that adversely impact the built environment, typically seismic or weather related. The events that arise from these hazards can vary significantly not only in respect to severity, but also geography. In turn this will determine the impact on public health and safety, property and infrastructure, and the natural systems within which they exist.

As previously discussed, the context for considering natural hazards and building climate resilience places the focus on weather related natural hazards. These are predicted to be influenced by future climate, such that they will become more intense, be longer in duration and have a different geographic spread. Amongst these known conditions, several are not under consideration given that their impacts on buildings represent a limited risk to public health and safety (e.g., hailstorms) or the natural forces are so severe that building standards will either be ineffective, involve the decommissioning of an area or require a level of infrastructure that would make construction impractical (e.g., extreme storm surge).

In all circumstances it is also important to remember that where codes and standards are applied, they cannot guarantee a hazard event will not result in the loss of life or injury, nor that building performance will be maintained through its design life, but rather the enforced building standards can mitigate the overall impact if the hazard event occurs.

Based on a combination of risk to public health and safety, and potential for structural property damage, four climate related natural hazards have been identified as initial priorities. This involves consideration of what technical building codes and standards may be able to offer towards mitigation beyond minimum requirements that might currently exist based on historic data (noting that depending on jurisdiction, different requirements will apply to different hazards). Of these four climate-related hazards, **extreme temperatures** is somewhat unique, considering these events do not necessarily have an association with property damage.

The three other identified extreme weather-related natural hazards that pose a significant risk to life and property, are **extreme wind** such as hurricanes, typhoons, cyclones and tornadoes, **wildfires/bushfires** and **extreme precipitation** (leading to severe flooding). It is also important to consider the potential for **multi-hazard events** and their impacts. For example, extreme winds can often be accompanied by severe or increased rain and hence flooding. In the instance of wildfires/bushfires, these events are often associated with periods of extreme heat, low humidity and strong winds. If electricity supply is impacted by the fires, it may hinder the ability to mechanically cool a property at a time when the demand for cooling may be at its peak, which has the potential to overload the power grid.

1.4.1 Scientific assessment

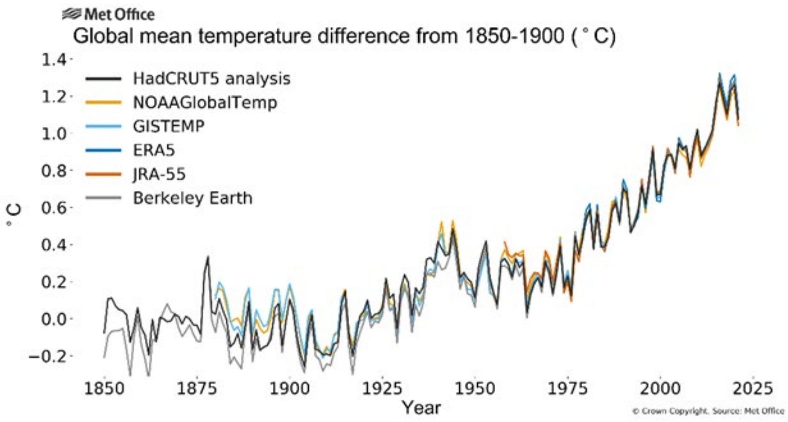
According to the World Meteorological Organization in its 2021 State of Climate report, the previous seven years were the warmest on record, leading United Nations Secretary-General Antonio Guterres to state "…the latest scientific evidence [shows] how our planet is changing before our eyes. From the ocean depths to mountain tops, from melting glaciers to relentless extreme weather events, ecosystems and communities around the globe are being devastated."[14]

The global annual mean temperature difference from preindustrial conditions (1850-1900) for six global data sets are captured in *Figure 5*, which not only shows the stark acceleration in temperature rise, but a high level of consistency in the data captured.[15]

[14] United Nations statement upon the release of the WMO State of Climate in 2021 report "State of Climate in 2021: Extreme Events and Major Impacts."

[15] World Meteorological Organization. 2021.

Figure 5



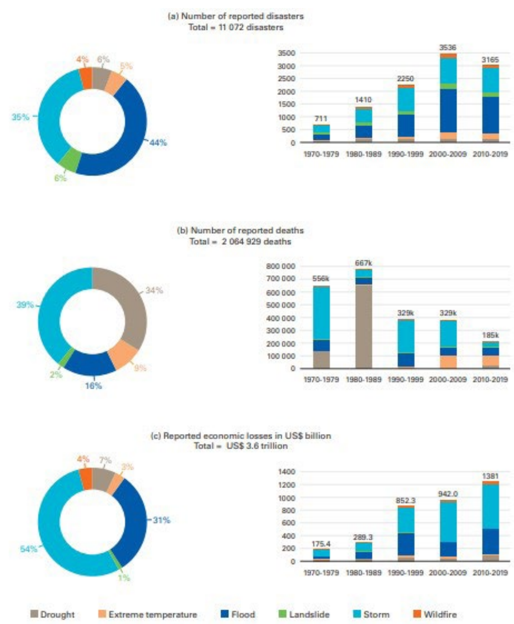
Source: World Meteorological Organization

According to 2018 data provided by the European Academies' Science Advisory Council, the number of floods and other hydrological events had quadrupled since 1980, with extreme temperatures, wildfires and meteorological events having doubled in the same period.[16]

The IPCC sixth assessment report also points to the increased incidence of extreme weather events since 1950 with high degrees of certainty on their links to climate change. The greatest level of confidence is for extreme heat, followed by extreme precipitation and wildfires, but less confidence in respect to extreme wind. This is due to an extraordinarily complex science, but still notes category 3 to 5 hurricanes/cyclones have increased in frequency over the past four decades, although this varies depending on geography.[17]

Figure 6 illustrates that the number of natural hazard events has increased significantly over the past 50 years,[18] with projections for further increases in the number, severity and geographic scope being predicted by international scientific and climate monitoring agencies. According to the United Nations Environment Programme (UNEP), climate change, combined with land-use changes, will result in an increase of extreme wildfires of up to 14% by 2030, 30% by the end of 2050 and 50% by the end of the century, including in areas such as the Arctic Circle.[19]

Figure 6 Distribution of disasters and impacts by hazard



Source: UNFCCC

[16] European Academies' Science Advisory Council, Leopoldina - Nationale Akademie der Wissenschaften. 2018.

[17] Arias, P.A., N. Bellouin, E. Coppola, R.G., et. al. 2021.

[18] United Nations. 2021.

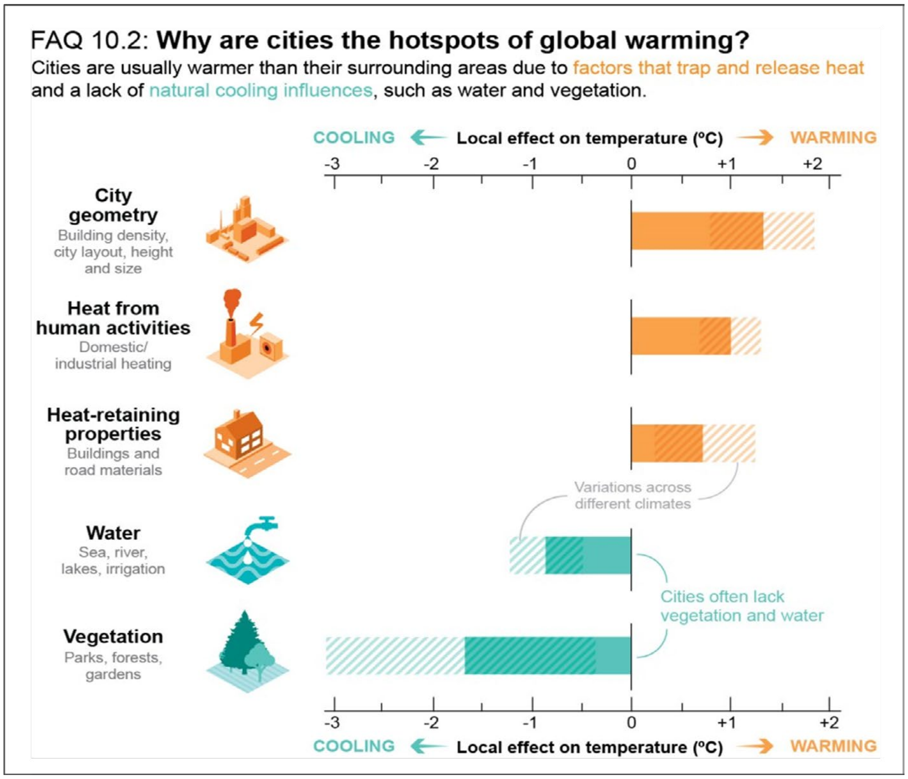
[19] United Nations. 2022.

Specifically in the context of the built environment, heavily urbanized areas are particularly vulnerable to extreme heat, known as the urban heat island effect, due to three main factors identified in the IPCC Fact Sheet:

- "Urban geometry: Tall buildings close to each other absorb and store heat and also reduce natural ventilation.
- Human activities: Due to heat released from domestic and industrial heating or cooling systems, running engines and other sources.
- The materials that make up cities: These materials are very good at absorbing and retaining heat and then re-emitting that heat at night."[20]

The IPCC concludes, with high confidence, that irrespective of the background characteristics of climate, the trend of future urbanization will compound the projected air temperature change in cities. How this translates into temperature differentials is illustrated in *Figure 7*.[21]

Figure 7



Source: IPCC Sixth Assessment Report Regional Fact Sheet – Urban Areas

One of the questions explored in the second Global Resiliency Dialogue survey was what representative concentration pathway (RCP) should be used in the consideration of future climate for code development. RCPs are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, which are consistent with a set of broad climate outcomes used by the climate modelling community. The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain because of additional greenhouse gases, measured in Watts per square metre (W/m^2).

The complexity of humanity's possible future emissions has been reduced to just four representative pathways. RCPs consider the impact of atmospheric concentrations of carbon dioxide and other greenhouse gases and aerosols (such as sulfate and soot). Each of the RCPs covers the 1850–2100 period. They include one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5 and RCP6) and one very high baseline emission scenario (RCP8.5). The 8.5 pathway arises from little effort to reduce emissions and represents a failure to curb warming by 2100.[22]

[20] Intergovernmental Panel on Climate Change. 2021.

[21] FAQ 10.2, Figure 1 from Doblas-Reyes, F.J., A.A. Sörensson, M. Almazroui, A. Dosio, W.J. Gutowski, R. Haarsma, R. Hamdi, B. Hewitson, W.-T. Kwon, B.L. Lamptey, D. Maraun, T.S. Stephenson, I. Takayabu, L. Terray, A. Turner, and Z. Zuo, 2021.

[22] Jubb, I., Canadell, P., and Dix, M. 2016.

The results of the Global Resiliency Dialogue Survey did not produce a consensus, perhaps underscoring the complexity of consideration involved. While RCP 8.5 is the current trajectory based on a continuation of the historical curve without taking significant action to reduce GHG emissions, it introduces a level of precaution and is not necessarily representative of minimum building performance. For this to be the case, RCP 4.5 would be more appropriate factoring in both an assumption that efforts to mitigate GHG emissions towards net zero carbon will gain momentum and that designing for RCP 8.5 needs to account for a diminishing return in terms of what can be achieved, having regard to the intensity of events under this scenario as well as broader implications for global society.

The choice of RCP when considering the incorporation of future climate into building design is important in relation to the expected service life of a building, since over the shorter term (<50 years) scenarios are similar, while in the longer term the scenarios diverge resulting in larger differences in design considerations.

1.5 DEFINING BUILDING RESILIENCE

Given that building codes are generally focused on achieving goals of life safety, amenity (comfort) and sustainability, there is a need to ensure that building resilience is placed in the right context to deliver better and achievable building outcomes. In failing to achieve an agreed definition of resilience in a building context, resources may be allocated inefficiently, regulatory tools may prove ineffective, unintended outcomes or consequences may be generated and a loss of public confidence may arise through the raising of unrealistic expectations, such as an asset not needing to be insured.

Some common elements of existing definitions that have been used for the resilience of buildings include:

Resilience…	Applied to buildings
Of what	Buildings or parts of buildings and the contribution this makes to the broader community.
To what	Future extreme weather events, which are anticipated to change in frequency, duration, intensity and/or distribution.
For how long	Before (i.e., adapt), during (i.e., durability) and after (i.e., recovery), short and longer term.
For whom	Health and safety of the following: 1. the intended occupants of the building, and 2. those who rely on essential systems, services, or infrastructure provided by or from the building

1.5.1 Structural Performance, Durability and Building Resilience

For the above reasons, the Global Resiliency Dialogue partners explored the merits of several existing definitions of resilience. This was discussed in the second Global Resiliency Dialogue survey to consider what might be adapted to provide the appropriate scope to do justice to the international building resilience challenge. One of these select definitions came from the CSA S6: 19 Canadian Highway Bridge Design Code (2019):

"Resilience: The ability of a structure or a component to withstand unexpected events (e.g., earthquake, traffic overload, natural or man-made hazards) and minimize loss of functionality and recovery time without being damaged to an extent that is disproportionate to the intensity of the events."

This definition builds upon the Canadian example, considering the inclusion of buildings alongside structures and components, and the replacement of 'unexpected events' with more relevant climate and hazard related ones. It is also important to bound the 'resilience to what' definitional element. While building codes cover multiple hazard types, the Global Resiliency Dialogue is currently focused on those hazards associated with climatic and weather-related events likely to be influenced by the changing climate.

A definition would also benefit by acknowledging that resilience needs to incorporate more than just a level of structural performance of buildings. There is also a need to enhance overall building performance. This could include some reference to preserving an equivalent level of building performance considering future changing climatic conditions as is currently achieved today.

This focus on performance can, however, be taken too far when having regard to the role of building codes. Some believe adopting a definition that could be interpreted as ensuring a building being completely weatherproof is appropriate. For example, in a tropical storm (be this a cyclone/hurricane/typhoon), a resilient building should withstand damage not only to the external aspects of a dwelling, but its internal features as well (or what might typically be referred to as 'property protection'). The rationale being that water damage to interiors of buildings is expensive and reducing such damage would go a long way to limit and reduce the insurance payments made to policy holders following climate related impacts.

Others might favour a definition that builds in a level of redundancy to account for what is often regarded as the 'precautionary principle' without accounting for the costs associated with constructing to an event that may not eventuate and applying that across society when such an event may never occur.

In this respect it is important to stress that building codes and standards are intended to provide a minimum level of performance (including in the case presented here for a level of resilience beyond life safety), while enabling individuals to choose to go beyond the base requirements. This is a practice of risk tolerance, in large part directed at prioritizing life over property, but also extending minimum resilience benefits to the majority through what is considered affordable (this will of course vary according to societal wealth).

Based on the existing definitions of resilience and the need for a definition specific to the climate-focused work relating to buildings, the Global Resiliency Dialogue supports the use of the following definition of building resilience to guide the development of these Guidelines:

"Building resilience: The ability of a building and its component parts to withstand current and future climatic conditions (including wildfires/bushfires, extreme wind, extreme precipitation and extreme temperature), to minimize the loss of functionality and recovery while sustaining damage proportionate to the intensity of the events experienced, and preserving the intended level of performance at the time of construction over the proposed design life of the building."

PART 2

The following sections are informed by the findings from the Global Resiliency Dialogue survey of building code stakeholders in Canada, Australia, New Zealand and the United States in the November 2021 report on "Delivering Climate Responsive Resilient Building Codes and Standards" and the four individual country volumes of survey responses and analysis.[23] For more detail, please review the full report here.

The sections covered in Part 2 provide information relating to the potential benefits that can be derived from building codes and standards that are assessed as being fit for purpose in addressing the areas of weather-related natural hazards identified in the Guidelines, as well as the known difficulties that are likely to be experienced with the nature of this subject. The latter includes:

- *Knowledge gaps and data*
- *Regulatory impact analysis*
- *Minimum levels of performance*
- *Land use planning*
- *Competing priorities*

The overwhelming takeaway from the second Global Resiliency Dialogue survey was building codes and standards that deliver improved building resilience would lead to:

- Improved public health, safety, wellbeing and community resilience;
- Reduced economic losses and protection of investments/assets (particularly for homeowners for whom their residence is one of the biggest investments they will make in their lifetime);
- Increased availability and reduced cost of insurance;
- Faster and less expensive recovery from disasters (including less displacement and need for social services, and fewer repair costs);
- Enhanced social stability, enabling improved ability to absorb shocks and disruptions and continue critical services and operations; and
- Improved building performance.

Increasingly, national policy frameworks recognize building resilience as an important feature of natural hazard mitigation in response to the effects of climate change. Therefore, building codes and standards play a key role in delivering outcomes that help mitigate the impacts of extreme weather events.

Drawing from some of the earlier evidence presented under *Section 1.4*, the increasing frequency and severity of weather-related natural hazard events is a driver for technical construction standards to be reviewed. Achieving enhanced resilience through forward-looking codes could help prevent loss of life, property and infrastructure damage, dislocation of communities and excessive costs of reconstruction, either borne by governments, individuals, or an increasingly uneasy insurance sector.

Greater confidence in predictive modelling and availability of data mapping the effects of climate change has resulted in an increased symmetry/alignment of government attitudes and policy at all levels that support the need for action. This is also supported by various national inquiries, the strong advocacy of emergency service authorities, private sector interests, not-for-profit organizations, research bodies and community leaders.

This shift in attitude provides the basis for a greater concentration of resources and expertise for building resilience, and provides the opportunity for an enhanced collaboration between the climate science and building science communities. This collaboration will be critical to solidify what represents a minimum technical standard to the predictive modelling of future climatic conditions.

The concentration of resources will also recognize the importance of many government agencies and national institutions operating at different levels and the importance of empowering experts and those responsible for implementing change to work collaboratively. This is increasingly being facilitated through national disaster mitigation strategies/frameworks or more specific policies that also look to establish a consistent reference point for climate mitigation and adaptation targets (e.g. the New Zealand Government's National Adaptation Plan, Australia's National Disaster Risk Reduction Framework, Canada's Pan Canadian Framework on Clean Growth and Climate Change, and America's Tackling the Climate Crisis at Home and Abroad in response to Executive Order 14008).

[23] Global Resiliency Dialogue. 2021a.

Using the World Bank's 'Triple Dividend' of Resilience framework there are three different types of benefits/dividends with respect to resilience and climate change, which includes strengthening building regulation as a key component of any disaster risk management strategy.[24]

- **Avoided losses:** Investing in disaster risk management (DRM) strategies takes the form of reduced losses and damages in the event of a natural hazard event. Most notably this includes lives saved along with prevented or reduced damage to assets.
- **Unlock economic potential:** Even the mere possibility of a future disaster has real impacts on present-day economic growth, particularly in regions or localities where disaster risks are perceived to be high. DRM measures help unlock economic development potential by enabling forward-looking planning and investment. Increased resilience can catalyze innovation, entrepreneurship and investment in productive assets – even if disasters do not occur for a long time.
- **Generate development co-benefits:** DRM investments are typically associated with economic, social and environmental uses, or 'co-benefits.' Co-benefits can play an important role in motivating DRM measures and determining their design (e.g., shelters doubling as community spaces or flood protection infrastructure doubling as roads).

2.1 OBSTACLES TO CODE AMENDMENTS

Technical building codes are developed for the purpose of their adoption as regulation and follow good practice processes to ensure they appropriately balance a variety of considerations, including societal expectations, risk and affordability. They also cover an increasingly varied number of subjects beyond their origins of preventing building fire spread and structural failure. In relative terms, extreme weather-related natural hazards are one of the more recent subjects covered by building codes, with the principal purpose of any adopted measures being to provide a reasonable level of protection for the occupants of a building during a damaging event, after which the building may be regarded as redundant.

As reflected in the definition of *building resilience*, the increased extremes of weather-related natural hazards that arise from the effects of global warming warrant re-consideration of regulatory settings, including the desired expectation for performance of a building to remain serviceable following a design weather-related event.

This poses a range of potential obstacles, including:

- switching from conventional practice of being reactive to damaging events in order to establish an evidence base
- using predictive science
- overcoming disconnection amongst the range of decision-makers involved
- setting clear roles and responsibilities
- addressing resilience in existing physical assets to which contemporary codes and standards will not apply
- assessing the economic impacts of regulatory changes considering the time horizons applying to the costs and benefits
- overcoming difficulty in shifting the attitudes of industry and public sentiment.

2.1.1 Knowledge Gaps and Data

The current state of climate science can be seen by some as limiting in designing for extreme events. Lack of understanding and ability to interpret climate data can lead to limited confidence in decision making, particularly where there is a deficit of knowledge and comprehension about the potential impacts, fragmented activities and uncertainty about best-practice solutions. In some cases, designers can account for extreme events, but are hard-pressed to determine and communicate the benefits of resilience to clients. Further, the impacts of some extreme events are not well accounted for in current weather and climate hazard models.

To address this, it is necessary in the first instance to fill specific knowledge gaps, where data and research can help:

- Better understand the intersections, interactions, and ways to balance different design goals including climate resilience, health, cost (including cost of sale, operation, and insurance) etc.;
- Determine the performance expected of current buildings in future climates, including extreme weather events, to develop a baseline for proposed changes to codes;
- Set limited metrics to consistently assess climate risks at as localized a scale (downscaled) as possible and invest in appropriate mitigation measures;
- Develop tests for future building systems to establish their performance under future climatic conditions and extreme weather events;

[24] Overseas Development Institute and World Bank Group. 2015.

- Establish an iterative process in alignment with global standards for updating climate science; and
- Ensure the effectiveness of future building systems and codes based on forward-looking science, to illuminate their growing need and value.

To understand how climatic conditions will interact with changes in building typology and construction methodology, reliable long term historic trends of climatic and environmental data are critical. This includes measured data and mapping of risk impacts (accounting for hazard, exposure and vulnerability), which will be of value to governments, industry, and communities as well as code developers. Modelling also needs to be conducted to identify potential climate impacts and trends for different global temperature levels, for different climate variables and for different regions. Much of this modelling has already been conducted, from a science perspective, showing alignment with the higher RCPs across numerous climate models.

Sharing of research into climate modelling and data analysis will help in comparing and improving the robustness of predictive climate science, and will drive international consensus towards establishing a consistent approach, albeit often applied at a regional or local level. Complementing this with research to establish predictive evidence specific to the four identified natural hazards of extreme heat, extreme wind, bushfires/wildfires and extreme precipitation, will be critical in determining the extent to which changes to codes may be necessary to help address extreme weather events.

A common theme identified in the survey responses was the need for improved availability of future climate data in formats suitable for government agencies, local government, building code and standards developers, other end users and the public, with a role for central government agencies to fund and curate said data. Related to any knowledge gap is the continual improvement in the science as the modelling gets better, which creates a constantly moving target associated with the expected impact of future weather-related hazards over the life of buildings. This alone results in a challenge to the established process of updating building codes, which has largely relied on the consistency and presumed predictability of historical data and proven scientific testing.

2.1.2 Regulatory Impact Analysis

A potential barrier to achieving increased levels of resilience is increased upfront building costs, as well as lack of industry capacity and expertise. Up-front cost is often seen as a barrier to improving building performance and resilience, even if the whole-of-life costs to the occupants and public are lower. There is also the challenge with ensuring costs are fairly distributed across society and amortizing costs falling on individual building owners if required to undertake expensive retrofits or upgrades.

Examining the impacts of regulation is an important feature of ensuring that good process yields balanced outcomes. The methods used for this type of analysis are well developed and should be applied independently to maintain high levels of impartiality and integrity in the conduct of this work.[25]

A regulatory impact analysis will often include consideration of the cost of re-building assets following a natural hazard event as some of the methods used can have a pre-disposition to economic weighting and analysis. Some of the impacts are less tangible following a natural hazard event, such as social dislocation and personal trauma. There is also a heavy reliance on what has occurred as opposed to what is anticipated to happen. The evidence of the past provides consistency and certainty while predictions of the future, are by definition uncertain and subject to fluctuations with time.

The commonly-applied current approach, based on historical data and research evidence, will not work well in establishing building regulations intended to incorporate features into new buildings that have the potential to experience a different climate with more extreme weather events than anticipated in the past. The corollary is to establish, in this type of impact analysis, minimum regulations that are proportional and cost-effective.

Some of the criteria for regulatory impact analysis in this area could include:

1. Consistent approaches for assessing a full range of impacts (social, economic, environmental). Consistency is also needed in addressing the vulnerability of specific buildings and identifying any appropriate interventions;
2. Distributional and compounding impacts across society;
3. Both initial and whole-of-life building costs considered from the perspectives of building owners/occupants and the public. When considering resilience options, the operational and embodied carbon emissions must also be considered, alongside unintended consequences, to ensure the solutions are optimal;
4. Consideration of co-benefits including non-financial co-benefits: building resilience can mean reduced energy bills (e.g. through energy efficiency, on-site generation), less displacement of individuals and communities, etc.;
5. Future property repair and reconstruction costs, which can be cyclical;

[25] Some examples include cost benefit analysis, distributional analysis, regulatory burden analysis, probability analysis, risk analysis, learning rates, discount rates, and sensitivity analysis.

6. Additional living expenses and other costs of residential displacement;
7. Future losses associated with business interruption, both direct and indirect;
8. Direct losses due to facility damage that leads to production loss, transportation delays, and communication interruptions;
9. Indirect losses due to value-chain interruptions, leading to revenue loss due to damage at other facilities;
10. Increased insurance costs and decreased tax revenues;
11. Costs for emergency response;
12. Loss of service to the community, especially to critical facilities including fire stations and hospitals;
13. Increased maintenance and repair costs;
14. Magnified negative public-health outcomes: deaths, non-fatal injuries and disability, and post-traumatic stress disorder;
15. Job losses and business failure, leading to diminishing job creation;
16. Historical and other cultural impacts;
17. Increased reliance on local services (e.g., solid waste management for hauling debris from damaged buildings);
18. Environmental impacts (e.g., soil, water, air contamination from building materials destroyed in wildfires, the GHG emissions from the disposal and premature replacement of failed materials and systems); and
19. Infrastructure lifespan (e.g., associated with better installation and maintenance of stormwater and wastewater infrastructure associated with reducing urban flood risk).

In addition, there exists a case to move codes forward and achieve cost effectiveness through initiative-taking measures for the lifecycle of a building having regard to its geographical vulnerability, as opposed to responding to past events. Whilst not without precedent, this represents a challenge for impact assessment, as it potentially calls upon the cost of installing features in a building that are not required for years or may never be necessary. Adopting low-cost measures where possible, or first addressing risks that are expected to materialize over shorter timeframes may achieve more favorable outcomes from cost/benefit analysis.

Good practice regulatory processes include the examination of non-regulatory options. In the case of extreme weather, it has been suggested by some that regulation should not prescribe the ways in which to achieve resilience. Local governments should instead determine what is financially feasible based on the risk to their particular jurisdiction. Depending on the nature of regulatory practice in the various jurisdictions, however, enhancing model codes or moving to "above code" or "stretch code" solutions can be sensitive due to considerations of industry uncertainty, a reduction in regulatory consistency, loss of productivity, price distortions, affordability and the like.

2.1.3 Minimum Level of Performance

The complexity of climate change presents a challenge for building code developers and designers to decide how much risk to assume given the relative lack of actionable risk data and the different potential future climate scenarios, which in turn dictate which climate models/projections to use.

The need to define what represents a clear minimum level of performance will be significantly influenced by the modelled science for the different types of natural hazards and their projected intensity, frequency and geographical occurrences. This will be further shaped by acceptance of what defines building resilience, as discussed above, as this will determine what can be considered proportional to both providing a reasonable level of protection to occupants and buildings, as well as a level of post-event performance of a building. Understanding these elements will help set parameters for technical feasibility and cost of measures.

The first challenge for establishing minimum performance is the need for clearer interpretation of the following aspects: (1) uncertainty in climate models;[26] and (2) degree of resilience for future risk mitigation. This includes noting that risks differ across the geographic scale (e.g., extreme wind, flooding, wildfire, extreme temperature) and in time scale, as some may increase in the coming decades while others may decrease.

[26] This can often be addressed by use of Confidence Levels in the scientific literature – see IPCC material as example.

The second challenge is to define the design objective in addressing changing climate loads and on which the following should be focused:

1. initial reliability;
2. minimum annual reliability;
3. average reliability over the design life;
4. reliability at the end of design life; or
5. minimum performance level throughout the structure's design life.

In all cases, reliability should not be lower than what is currently acceptable if such measures already exist. For example, if the current levels of performance provided by one particular jurisdiction's codes for wind includes a load factor (safety factor) of 3.0, this will result in a certain probability of failure over the service life of a building. Reliability under future non-stationary climate loads should not carry a higher probability of failure than this (which is currently considered adequate).

Most current codes do not treat durability as a primary design goal and address resistance to deterioration to a degree through individual material standards to achieve the current objectives. Regulating for durability in a changing climate may require new objectives and a definition of design life.

Building codes typically apply at the time of construction and therefore do not take into consideration changes that occur over the lifespan of the building, such as wear and levels of maintenance. In the same manner, codes usually apply to new buildings and new building works rather than existing structures. Exceptions include the International Code Council's International Existing Building Code and International Property Maintenance Code.

Establishing what should be considered the minimum level of performance also requires clearer guidance to support code change requests, guide and justify climate adaptation investment decisions and account for the ability of contractors, builders and the supply chain to adapt to the changing regulatory landscape. Significant training and education of trades and professions will also be needed to ensure codes are applied consistently and as intended. Effectively harnessing compliance and inspection measures also ensures structures and the materials used comply with adopted codes and standards. Separately, there is an opportunity for building designers and clients to be educated about the options and potential benefits of going beyond the minimum requirements.

2.1.4 Land Use Planning

Decisions about where buildings can be located are made through the land use planning processes that operate across jurisdictions. These are typically operated by local governments, where the framework within which these authorities reach decisions, whilst capable of being influenced by policy settings established by higher levels of government, have a high degree of autonomy to set their own rules and make decisions on development within their area.

There are many factors that will influence land use planning decisions, including land use zoning and any associated overlay controls, geological and environmental conditions, cultural or heritage listings, infrastructure availability, property entitlements, economic considerations, and in many cases the inputs of government agencies, individuals and representative bodies.

The future climate and the risks it may represent to property development are not always considered factors in land use planning decisions. Large areas where decisions to enable development have already been made, but where there will be a latency in risks when building occurs, must be accounted for. There are also many established areas prone to the risks of extreme weather events where new development or redevelopment can occur.

In some cases, there is a direct relationship between conditions of development in areas prone to extreme weather events and the construction standards that must be applied. However, there can also be inconsistency through variability in minimum levels and methods applied through the discretion that authorities having jurisdiction may be able to exercise. It is possible in some jurisdictions for planning ordinances to set different or defacto levels of building control over those contained within recognized building codes and standards.

Land use planning policies, including the zoning of land for future development, are often not the subject of regulatory impact analysis, where factoring in the implications of permitting development in areas likely to be prone to future natural hazard events may otherwise rule out such development or recommend that more stringent levels of construction would be warranted. If this were the case, however, suitable construction standards may not exist. Therefore, allowing buildings in areas of increased vulnerability can disproportionately raise expectations that the construction standards will keep occupants safe and buildings in a good state of repair. As stated earlier, building codes should not be regarded as a cure all to the building vulnerabilities that will arise in some locations.

2.1.5 Competing Priorities

Most systems in place for the development of building codes have limited resources to address competing priorities, while necessarily moving at a deliberate pace in order to properly assess the impacts of code changes having regard to the views of diverse stakeholders. In emerging economies this can be further compounded by capacity limitations to ensure effective implementation and enforcement of building codes.

Depending on the nature of the code development body, priorities will be set by governments, boards or other forms of decision-making authority, having regard to societal needs, emerging issues, the requirements of industry and whatever risks may present themselves at a particular point in time. An example is the risk posed by combustible external wall systems highlighted through several international incidents, the most significant of which being the Grenfell Tower fire in London.

The processes to amend building codes are such that there is often a long lead time in conducting the necessary policy research, consultation and impact analysis, as well as developing proficient technical provisions. When combined with industry capacity to engage in and absorb broad regulatory change, invariably, limitations are present on how much can be achieved within every code cycle.

In the case of building resilience, there is competition with many other significant policy and administrative settings, including structural and fire safety systems, energy efficiency, accessibility, weatherproofing, product performance and building maintenance.

At a broader political level, there are competing priorities for the allocation of resources, which are often driven by short-term issues or interests. This can lead to resistance in financing the potential higher upfront costs of increased resiliency features. Likewise, this approach can detract from offering incentives for consumers and builders to adopt additional attributes to improve the resilience of buildings, indicating a general lack of public awareness of climate change impacts. Instead, the market is skewed to delivering buildings that are lower in initial cost and contain attractive attributes, without an understanding of or regard for the construction practices employed and the potentially detrimental consequences of having foregone built-in resilience features.

3.1 Purpose

The Global Building Resilience Guidelines are organized around fifteen principles that provide a basis for advancing building resilience through building codes. They are intended to help inform the development of building codes and standards that incorporate future-focused climate resilience. The Guidelines are relevant for all building code and standards writing bodies, who will determine how best to apply them having regard to their own jurisdictional circumstances.[27]

It is important to note that where codes and standards are applied, they cannot guarantee a hazard event will not result in the loss of life or injury, nor that building performance will be maintained through its design life, but rather they can mitigate the overall impact of such event occurrences.

The principles are not weighted, but there is an intentional order as inevitably there are inherent interdependencies:

1. Urgency
2. Clarity of objectives
3. Robust climate science
4. Risk clarity
5. Forward-looking
6. Durability
7. Holistic approach
8. Affordability
9. Existing buildings
10. Building maintenance
11. Compliance
12. Implementation
13. Monitor and evaluate
14. Engagement
15. Emissions reductions

Principle 1: Urgency

Principle: The need to respond to the associated impacts of climate change and extreme weather events on buildings and building occupants is more urgent than ever.

Communities around the globe are already experiencing the impacts of climate change. As buildings are the foundation of social and economic function throughout society, and as rapid urbanization continues, there is an urgent need to address the vulnerabilities of communities and the risks to the services provided by the built environment from natural hazard events linked to climate change.

The Global Alliance for Building and Construction (GlobalABC) published a guidance document in October 2021, *Adaptation of the Building Sector to Climate Change: 10 Principles for Effective Action*, which lays out key principles and calls on policymakers and practitioners to adopt climate change adaptation actions in the building sector. Through the report, urgency was identified as a core principle to the climate crisis and building resilience actions, highlighting the critical functions of buildings serving society.[28] This principle calls for implementation of tangible climate action plans for buildings as soon as possible, which directly relates to the themes established within these Resilience Guidelines.

Climate change and the associated impacts, including natural hazard events, have continued to increase in severity, frequency and losses accumulated. The need for action is more urgent than ever. Building code regulation has a critical role to play in helping address the potential risks of future-climate disaster events. This can be through providing health and safety functions, as well as continued operational function (i.e., improved *building resilience*) to support comprehensive community resilience.

Principle 2: Clarity of objectives

Principle: Building resilience requires attention to the changing climatic conditions buildings will face over their lifecycle and their expected operation following an extreme weather event. The importance of building codes focusing on occupant health and safety remains.

Occupant health and safety should remain the primary purpose of building code provisions. However, as per the Guidelines' definition for building resilience, enabling a level of building robustness beyond occupant health and safety is considered appropriate within the bounds of the minimum necessary, having regard to the climate-related natural hazard events that may reasonably be expected. This can help communities to quickly resume their daily activities, economies to recover and help make the cost of recovery more manageable.

It should be acknowledged that for those codes that already include provisions and referenced standards designed to protect the occupants of buildings from extreme weather events, these will invariably result in a secondary benefit of improved building resilience.

[27] Content for the Guidelines has been garnered from those who participated in the Global Resiliency Dialogue, the work of others in this field and the findings from the two Global Resiliency Dialogue surveys, which reflect the input and views of a diverse range of stakeholders who have a direct interest in and capability to contribute to the subject.

[28] French Agency for Ecological Transition, Resallience, and French Ministry of Ecological Transition. 2022.

Although a building code's focus should remain on supporting the objective to keep building occupants safe, protecting the structure well enough to ensure it remains safe and serviceable in cases when the service environment (exterior climate) changes, becomes an additional factor for consideration as part of building resilience. In this manner, as the building's service environment changes, ideally so will the requirements. The objective is to ensure that the level of building performance remains acceptable.

Given that building codes have multiple objectives, they invariably cover many subjects. It is therefore important that in both understanding and developing suitable responses to a subject, the relationship between measures is properly understood to avoid the potential for unintended consequences.

Many building codes already include sustainability as one of their objectives. Whilst this may traditionally be viewed in the context of energy efficiency and water conservation, the resilience of buildings that enables communities to better respond to the impacts of an extreme weather event and reduce the costs to society so it can be redirected to other recovery efforts, can be seen as related to more sustainable practice.

Irrespective of objectives, the challenge with future climate uncertainty is how it can be addressed in codes today. This may best be achieved through a different type of statistical model or probability analysis that ties to facility importance/operational criticality, overlaid with the impact of a proposed/triggered code change on resiliency measured against cost. Successful management of uncertainty, such as in seismic code provisions, can provide lessons for achieving resilience tied to climate change uncertainty and shifting hazard severity.

This type of modelling within codes will likely involve a degree of complexity and competence on the part of professional practitioners in its application. Therefore, once it is established it will need to be very clearly and concisely communicated, including on what basis it is made (i.e., data sources, variables considered, known biases, and what is/is not included in the model).

Models are also parts of climate ensembles that will need to be distilled down to only a few scenarios to provide a degree of simplification. It should also enable evolution as conditions change. There will always be uncertainty and this necessitates the need to communicate the evolution of the process as opposed to the 'one and done' aspect of any model used. Use of this type of modelling may be best applied to inform nearer-term changes and avoid huge costs driven by expanding uncertainty over longer timeframes. Thus, new buildings with performance goals for longer design life than code minimums can be designed and address likely variances.

Principle 3: Robust climate science

Principle: Building code development will benefit from an evidence base that utilizes official climate forecasts in the local jurisdiction or models based on peer-reviewed scientific research and ideally provide a demonstration of various future state possibilities.

For buildings being constructed or substantially renovated from this point in time to provide an appropriate level of building resilience, it is necessary for contemporary building codes and standards to be developed or revised having regard to future climate projections and scenarios from scientific sources. In doing so, there will need to be a transition from historic to predicted climate data to address future risk. This transition must take account of frequency, severity and probable changes to geographic distribution, including routine reviews to maintain fitness for purpose with the latest climate science.

The GlobalABC's *10 Principles* identifies that *"those seeking to employ forward-looking climate risk data in the service of adaptive planning need to learn about, understand, and critically use such data taking into account uncertainty. Tools to make climate risk data more understandable and accessible to stakeholders across the whole value chain need to be developed."*[29]

The most reliable information is often aggregated from multiple sources at a national or provincial level depending on jurisdictional responsibilities and capacities. However, given the variety of climatic conditions across countries and that a one-size-fits-all approach will not necessarily be technically pertinent or cost effective as a result, there is likely to be a need for more localized models. These will ideally utilize baselines that are agreed upon by both climate and building scientists. This also aligns with the GlobalABC principle relating to adaptation measures being designed to fit with the local context.

The use of climate scenarios and data developed at a national level enables a policy approach to be developed that can be applied granularly at the local level based on the distribution of risk. Building codes and planning instruments will often employ data aggregated at a national or provincial level. In doing so, they will typically look to employ such data locally having regard to more specific on-ground conditions, such as for wildfire or flooding.

The quality and source of climate data and projections is critical to developing and maintaining weather-related natural hazard maps to educate and assist regulatory decision-makers in where to apply relevant natural hazard standards for buildings, which may include land-use planning instruments.

[29] French Agency for Ecological Transition, Resallience, and French Ministry of Ecological Transition. 2022.

Resilience actions need to be evidence-based and informed by advances in climate-science, enhanced knowledge of future climate-loads and their impact on buildings. Additionally, the proving of new technology and guidance will help support these actions and ensure the selection of appropriate climate adaptation measures.

Research data must be translated into forms and formats that are actionable in code development and understandable by designers. As is the case with fire and seismic communities of interest, it will be important to mobilize an enthusiasm to develop code language that successfully incorporates the latest research.

Not everything, however, must be formulated for the purpose of normative regulation. Science lends itself well to the development of more informative material to accompany code provisions and standards. Written in the form of guidelines and made easily accessible, this material can often assist in explaining the science.

The non-stationary nature of climate change also needs to be captured in the design of codes and standards by considering it probabilistically. Initial efforts have been undertaken to consider climate instability in the development of climate change provisions for the National Building Code of Canada and CSA S6: 19 Canadian Highway Bridge Design Code.[30] Additionally, the recently published American Society of Civil Engineers' Manual of Practice 140 on Climate Resilient Design includes guidance for the implementation of uncertainty and non-stationarity.[31]

The building science required to protect the structure well enough to ensure it remains safe and serviceable in cases when the service environment changes (exterior climate) will need to remain cognizant of supporting a code's principal purpose, to keep the occupants safe. In this manner, as the building's service environment changes, so should the requirements. The objective is to ensure that the level of building performance remains acceptable.

Importantly, the perceived need for additional research should not understate the existence of significant research that has already been undertaken in climate modelling by government entities, universities, research institutes, non-government organizations and the scientific community.

Principle 4: Risk clarity

Principle: Risk informed thinking and decision making is important in providing support for design decisions to balance cost, energy performance, greenhouse gas emissions and resilience, where changing risks can be balanced against certainty of performance for building development and maintenance.

Intrinsically linked to the science is the need to consider the level of risk in the design of codes, noting that the interaction with land-use planning may already have pre-determined a level of risk for the location of a building.

Risk will inform the minimum level of performance considered desirable. In turn, this becomes the goal for buildings to achieve, be it through prescribed standards or unique performance solutions that can demonstrate compliance. To further understand this relationship it is necessary to separate the goal into two parts.

The first is establishing a position to incorporate *building resilience* into technical codes in the same way other subjects such as structural stability, protection from fire, disability access and energy efficiency are incorporated. Each of these subjects has a risk profile of some nature. The second part is the stringency at which the technical provisions are established. This brings together the balance between:

- minimum performance necessary to achieve the desired objective
- the level of risk mitigation that can be achieved
- the ability to develop proficient technical standards to deliver the desired outcomes.

Key challenges include unpredictability and gaps in understanding how risks impact existing and future buildings, and the ability to influence performance both before and throughout the life of a building. As previously discussed, the application of risk in the context of building resilience takes on the added consideration of risk to a building's performance throughout its lifecycle in addition to the convention of risk to occupants.

The potential for climate change to increase the risk from spread of diseases currently absent from various geographies is an example of risk to occupants, for which applying the link to building design and technical construction standards may require examination in the future. The risk of waterborne disease, with water pooling around houses and disruption to safe drinking water following a severe flood, is well known to present a high risk of enabling the spread of disease-carrying insects, such as mosquitoes. The opportunity here is to think about how building regulatory systems could stipulate simple modifications to reduce house entry by, for instance, malaria vectors, such as closing eaves and screening doors and windows.

It is important to make informed decisions based on code minimums and risk tolerance in order to avoid the impulse to over-engineer the response, which has the potential to lock in excess embodied carbon and high costs. Conversely, underestimating the threat posed by extreme weather events has the potential to contribute to significant building failures in the future.

[30] Cannon, A.J., Jeong, D.I., Zhang, X., and Zwiers, F.W. 2020.

[31] Ayyub, B.M. (ed.). 2018.

How to approach the risk posed by extreme weather events in the design of buildings in a non-stationary climate will inform decisions regarding which design approach to take. Changing risks need to be balanced against certainty of performance for building development and maintenance. Context specific approaches based on thresholds for change is one method, but how to include regulatory requirements to monitor changes in climatic conditions and climate risk is potentially tricky.

Two potential approaches are:

1. Uniform-risk based design that strives to achieve uniform and acceptable risk of failure of buildings. This would require overcoming challenges with extrapolation and uncertainty in climate models.
   i. Risk based approaches to design could be required in core public buildings; and
   ii. Some performance-based design requirements could include climate data from datasets that include the most up-to-date climate information.
2. A more flexible approach would be to recognize the difficulty in quantifying all relevant sources of uncertainty in climate change projections. It would lead to estimating sources of uncertainty such as natural unforced climate variability. It would consider that extreme value distributions do not need to be probed as deeply (increasing confidence that it might be possible to capture climate change induced changes); and would rely on expert judgement from both engineers and climate scientists to adjust load factors as necessary. However, design that is left to judgement without clear guidance could result in different interpretations and lead to enforcement issues.

Going forward it is likely that a hybrid approach will need to be followed (i.e., a mixture of both methods).

A clearer understanding of risk will go a long way towards providing support for design decisions to balance cost, energy performance, GHG emissions and resilience. This can be approached through tools such as life-cycle assessment or analysis (LCA) and life-cycle cost analysis (LCCA), which still need to provide a full account of:

1. Costs and benefits in terms of social capital (including direct losses, but also all downstream implications for society including displacement, employment, etc.) to advise discussions and justify investment in resilience; and
2. Co-benefits of adaptation measures to health, energy, environment, economy and social systems to support code adoption.

Pilot studies can help to demonstrate the benefit of implementing resilient design from the start. At present, a stepwise adaptation approach is worth considering. This can enhance the ability to modify a building design with ease in order to adjust to new climate loads and the risks they represent beyond any previously accepted tolerances. This approach has the potential to lessen the investments required up front and to spread adaptation costs throughout the design life of the building, and only as needed.

Irrespective of a building's significance or occupancy type, the distinction in risk is made depending on the expected frequency of occurrence of the forecasted climatic impact. For most building types, the significance factor should therefore remain the same; there is no need to change types of buildings or their importance due to a change in external loads.

There are considerations for critical buildings that may be needed post-disaster, which should be designed to have continued function after an extreme event. One example is those buildings specifically nominated to perform as community refuges or emergency shelters in the event of extreme weather conditions, where higher levels of resilience will be necessary and expected.

Due to the complex nature of the built environment and the challenges faced, leaving scope for engineered initiatives alongside specified construction standards is desirable. To do so, codes can provide tools for designers, such as the following three options:

1. Use different importance factors for different occupancy types as exists today in some building codes;
2. Define appropriate and different reliability indices or probabilities of failure for different occupancy types of buildings; and
3. Define appropriate ultimate return periods for different occupancy types of buildings.

In this manner, critical buildings would benefit from protection against failure, enforced by regulation based on criticality and presence of vulnerable populations. For example, parameters such as permissible maximum indoor temperature could be defined for multi-storey residential buildings, schools and healthcare facilities, with special provisions to ensure mobility of senior populations or populations with disabilities.

By contrast, for the construction of housing, a mix of prescriptive (construction) and simple performance (design) approaches is necessary, as having a team of engineers or specialists on board is not a feasible, affordable or a reasonable approach for every project.

Principle 5: Forward-looking

Principle: A baseline assessment of current technical construction standards, where they exist, enables a comparison to be made with modelling and scenarios for future climate to help determine if they remain adequate or new ones need to be developed.

On the basis that contemporary codes will typically incorporate provisions for construction in areas prone to natural hazard events, including those influenced by climate, as a matter of good regulatory practice it is important to determine if existing requirements are adequate for future risks. This again brings into focus the need to acknowledge the potential impacts of future climate upon buildings being constructed today and what can be considered a reasonable design life.

There will be two immediate considerations here, with the first being the science and data that has been relied upon to establish existing standards and secondly whether they cover the scope of *building resilience* necessary from a code perspective.

Establishing a baseline assessment of current standards, where they exist, will enable a comparison to be made with modelling and scenarios for future climate to help determine if they remain adequate or new ones need to be developed. Where a standard does not exist, such as for heat stress, the baseline can be derived from a linear analysis of current data with future projections.

The baseline will need to have regard to the adequacy of both a code's policy targets, which may be in the form of quantitative or qualitative performance requirements, as well as any prescriptive settings that exist for the purpose of demonstrating compliance.

On the basis that changes are considered necessary through analysis against the science, a third factor will be developing the policy and technical requirements for which new construction will be expected to comply to achieve higher levels of *building resilience*. Whilst it can be expected that this will follow the normal processes associated with code/standards development and revision, there will be a high dependence on the reliability of the science and sophistication of its application geographically to minimize cost.

This can be expected to involve maps for the different natural hazards having regard to their changing geographic distribution and varying intensity over time. An adjunct to this will involve how requirements are applied. The two most obvious and tested methods are climate zones and files embedded within the code and its referenced standards, or natural hazard mapping undertaken by local government (or equivalent) to which the minimum requirements of the code are then adopted.

Given that the level of confidence in the science for the different types of natural hazards varies and will change as monitoring the effects of climate change and GHG emissions continues, step changes would allow time for adjustment and improve the chance of success. It should also be anticipated that there will be both complexity and many potential solutions. It is therefore preferable to enable flexibility, with prescriptive options available for mainstream construction and those who may not have the means to invest in unique or alternative forms of demonstrating compliance.

The co-development of new and/or existing code provisions and revised standards for these circumstances, through international collaboration, has the potential to help corroborate the outputs based on a broader scientific base, common experience and shared capabilities. It will also be necessary to monitor their performance alongside the evolution of the science to ensure the codes and standards remain fit for purpose.

Principle 6: Durability

Principle: Understanding building design life[32] is important not only to assist in determining minimum necessary technical construction standards, but to also calibrate the technical design requirements. This will help improve the resilience of buildings with a benchmark of durability that avoids unnecessarily harsh requirements and therefore costs.

There are strong arguments to be made for baseline resiliency consideration to be aligned with the expected life of a building when subjected to reasonable maintenance, particularly the expected life of a building before major repair and/or recapitalization occurs, often described as the design life. This design life, which will typically span well beyond the average period of a building occupant, should also consider the realistic life (service life) of the building and its sub-components, since they are generally used for longer than their anticipated life during design.

[32] Design life is the forecast life expectancy, in this case of a building and its components and systems, based on their design. Service life is the forecast life expectancy based on real world results. Design life is theoretical. When a building is first designed engineers can calculate how long it might last based on expected conditions, uses and physical properties.

The relevant projections of future climatic data depend on the design life or planning horizon. It can be anticipated that the longer the design life or planning horizon, the greater the temperature change, the greater the precipitation change and the greater the change in wind for some regions. It is therefore necessary to define the design life of a building to correlate the relevant climatic design data, since the climate is not stationary, requiring building codes and technical construction standards to be the subject of constant review.

By way of example:

- Wildfires are occurring in locations in the northern hemisphere that have not previously experienced them, such as regions proximate to where the Artic Circle is near the tree line.
- The interior of British Columbia reached record heat in the summer of 2021, and the city of Gatineau Quebec experienced two 1 in 100-year flooding events in the span of three years – resulting in flooding maps needing to be redrawn.
- In the Australian summer of 2022, the town of Lismore experienced a 1 in 3,500-year flood event topping its 10 meter high flood mitigation levy, only to be followed by another similar event within the space of a month.

These and other similar events cannot be accounted or designed for when referring to historic data alone.

An added feature of design life, which will be relevant to the improved resilience of buildings to weather-related natural hazards, is that the service life of some of a building's components and systems will be different. It is likely that many of these will have a shorter service life than that of the building, yet may be critical to the overall performance of the building during an extreme weather event. This necessitates the building to be viewed as a system and links to the importance of building maintenance in Principle 10.

Design life is not currently a typical feature of building codes, however, there is some broad consensus around distinguishing different design life for categories of buildings and a general range in life of between 25 and 100 years depending on its intended purpose. In doing so, a balance between durability, environmental impact and cost is necessary.

Existing material from the Global Resiliency Dialogue partners points to a level of consistency in identifying three categories of design life for different building types with a default of 50 years minimum, but always with the option for building owners to choose longer lifetimes.

This is best reflected in an extract from the Canadian Standards Association's standard on durability in buildings (CSA S478), reproduced in part as *Figure 8.*[33] The standard sets forth minimum requirements to assist designers in creating durable buildings. In addition, other annexes to the Standard provide general guidance on the environmental and added design factors that have an impact on the durability of a building, a building material, and/or a building component.

Figure 8

Design service life category	Building type	Minimum design service life	Range of design service life
Medium life	Low-rise commercial and office buildings / Stand-alone parking structures / High Hazard Industrial buildings	25 years	25 to 50 years
Long life	Single-unit residential / multi-unit residential / Mid- and high-rise commercial and office buildings, post-disaster buildings	50 years	50 to 99 years
Permanent	Monumental and heritage buildings	100 years	100 to 300 years

Source: Table extract, CSA S478:19, Durability in buildings. © 2019 Canadian Standards Association. (Please visit store.csagroup.org).

Although there is a general correlation between the category of building service life and the importance level of a building, the concepts should not be confused. An important (monumental) structure may have a short service life and an unimportant building may have a long service life.[34]

In terms of the ideal expected service life of different building systems and materials, the design life of a specific material or a component should be considered with the corrosivity of the surrounding atmosphere, building microenvironments, usage, function and maintenance requirements.

[33] CSA Group. 2019.

[34] Australian Building Codes Board. 2002.

In general, any increase in design life should be specifically proposed and justified, however, in practice, there is a limit to what codes can achieve based on estimated or desired service life expectations. One limitation already noted, is that building components have a different service life, whether by themselves or as part of assemblies. To avoid any 'wasted durability,' it is imperative that designs take this into account to allow for ease of renewals, maintenance and replacement so as not to affect other systems with much longer service lives.

Looking more specifically at the expected service life of different systems and building materials, some insight was provided through the responses received from U.S. respondents to the second survey, including:

- Envelope (windows/roofs/walls) – 30 to 75 years
- Subparts (non-envelope) – 20 to 30 years
- HVAC – 15 to 25 years
- Lighting – 15 years
- Controls - < 10 years

The wide ranges account for varying quality and durability of materials used and the risk hazard level in the region in which the building is located. Additionally, extreme events will reduce service life of roofing and cladding, for instance, if they are not designed for the loads and exposure endured.

Non-stationary climate in codes could effectively be addressed by:

- Including a climate resiliency assessment calculation when buildings are recapitalized or remodeled
- Designing for adaptability, passive survivability and/or reuse
- Incorporating the true useful life expectancy of projects

Including a form of 'vulnerability assessment' when buildings are recapitalized or remodeled, designing for adaptability, passive survivability and/or reuse, and incorporating the true useful life expectancy of projects, could effectively address non-stationary climate in codes. Increasing the use of modular components that can be easily replaced could also potentially enable adaptation to changing resiliency needs over a building's service life.

Principle 7: Holistic approach

Principle: Building codes can contribute to improving building resilience as part of a broad suite of regulatory and non-regulatory measures. In some cases this will be inter-dependent and take account of multi-hazard weather related events.

Building codes and standards are only part of the answer to achieving improved resilience to extreme weather events in the built environment and it is important they are not thought of as all-encompassing solutions. They are imperfect instruments for such a complex and varied challenge, and it would be folly to rely solely upon them as the means to achieving resilience. Therefore, these instruments are one of several levers, albeit an important one.

Despite this, building codes will need to consider all relevant content to determine if more can be done through the combination of measures to provide the best means for helping address building resilience. Due to the complexity and breadth of regulatory and non-regulatory measures, consideration as to how these are coordinated and communicated is important. This needs to include consideration for the potential impacts of multi-hazard events given they may cut across a broader range of measures and resulting in the need for some to be prioritized over others, including those that are not related to building resilience.

Moving beyond building regulation, society needs 'the right buildings in the right places,' since 'how' we build also needs to take into consideration 'where' we build. The two are complementary and address the desire to build higher levels of resilience in the built environment. This is where building codes and the planning system intersect most.

The resource management and planning systems need to be responsive to climate change and prevent buildings being constructed in locations where climate change will exacerbate natural hazards and risk damage and stranded assets. It is at the land use planning stage where masterplans and other related documents are developed for the design of new communities, associated buildings and infrastructure. Given this fact, land use planning can have a substantial impact on the level of resilience that can be achieved when it comes to the built environment. This includes moving structures out of flood prone areas by either relocation or raising the structure beyond the base flood elevation.

Early in the design of new and expanding communities, as well as maintenance of existing, there is an opportunity to consider many factors including weather-related natural hazard events. These considerations can be used to inform where development should occur and if a natural hazard cannot be avoided, how buildings and infrastructure can be made more resilient. Another example is powerlines in areas prone to wildfire, which can be placed underground, minimizing the instance of wildfire ignition and loss of critical infrastructure and function. In turn, building control systems can and do provide complementary tools to assist in setting higher standards for construction in areas that, under the planning system, permit development that may be or become vulnerable to natural hazards.

Policymakers can also have a huge impact by preventing overdevelopment and discouraging building in high-risk areas (which has not always been done in the past), while enabling people to relocate to areas and/or buildings of greater resilience – essentially making resilience more equitable. This can be achieved through cost-benefit analysis and has the potential to result in the reconsideration of land use, coastal development and managed retreat policies, inclusive of decommissioning.

Expanded development and use of building-level resilience benchmarks that can be understood by the public, like the International Finance Corporation's Building Resilience Index[35], could provide a powerful incentive for builders and developers to exceed code requirements driven by public demand.[36]

Depending on the type of natural hazard, a building's resilience can be enhanced, or compromised, through several external factors. For instance, having established wildfire management plans that aim to reduce fuel loads through hazard reduction burns, well maintained clearance zones, creating defensible space through the removal of flammable materials adjacent to homes and ensuring doors and windows are not left ajar in the event of a fire can all contribute to enabling a building to perform as intended in areas prone to wildfires.

Similarly, in high wind hazard areas, activities that minimize the potential for wind borne debris to function as projectiles that can penetrate buildings is significant and involves the consciousness of entire communities. This also involves regular maintenance of buildings to reduce the likelihood of materials becoming airborne simply because they are not properly tied down.

As noted previously, the urban heat island effect created through intense urbanization, exaggerates hot temperatures from the surrounding environment. The relationship between the design of buildings, the materials used, opportunity for passive cooling ventilation, the spatial distribution of buildings, urban tree canopies and the overall planning of cities need to complement each other to counteract this phenomenon.

Another key inter-dependence for buildings and cities in general is the supporting infrastructure of roads, power grids, water and drainage. This critical infrastructure, whilst not the subject of building regulation, is equally vulnerable to the impacts of weather-related natural hazards and can in turn severely impact the functionality of buildings and in particular critical systems. This can be compounded in multi-hazard type events, also diminishing the effectiveness of first responders.

Putting this inter-relationship in context helps broaden the understanding of opportunities to work collaboratively to identify strategies that might involve mutually supportive approaches to both reduce the causes of the urban heat island effect as well as better prepare for its impacts and that of other extreme weather-related events.

Non-regulatory levers such as information and guidance (e.g., a web portal) that can be used to drive interest and momentum towards more climate resilient buildings can help inform consumers as well as builders. In respect to the latter, industry membership bodies can promote building practices that incorporate any specific technical code measures designed to improve *building resilience*.

The market is increasingly playing a significant role in guiding where and how development that is prone to extreme weather events is conducted. Most notably is the availability and cost of insurance, which can determine the feasibility of building in high natural hazard risk areas. This places risk in the consumers' hands. Increasingly, financial institutions will play a greater role in the market in determining the potential of exposure to defaulting on loans where buildings may not be insured or are under-insured.

Principle 8: Affordability

Principle: Building codes and standards consider, where possible, a regulatory principle of setting minimum requirements necessary to achieve the level of desired performance and cost effectively. This should also achieve the objective of improved building resilience throughout the design life of a building under a range of future scenarios.

Building codes and standards need to maintain the regulatory principle of setting the minimum requirements necessary to achieve the level of desired performance, cost effectively. This process is designed to balance societal needs against societal capacity to pay, which at one level is an economy-wide application, and at another a household.

Regulatory impact analysis will explore building resiliency measures at both these levels to determine whether the additional costs will outweigh the anticipated benefits. As discussed earlier, this needs to account for a range of other considerations, such as the distributional costs and benefits, which will likely vary according to the natural hazard and risk involved. Whole-of-life considerations on this subject will also be important given the likely increased upfront costs to help make buildings more resilient to future events and the economic, social and environmental benefits that flow from this.

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[35] International Finance Corporation. 2021.

[36] Current building-level resilience rating systems in the U.S. include RELi for multiple hazards while the U.S. Resiliency Council and REDi support seismic resilience assessments. At the community level, the Alliance for National & Community Resilience (ANCR) includes a buildings benchmark in its Community Resilience Benchmarks.

Affordability is typically associated with places of residence, but is directly attributable to the ability of an individual to construct or purchase a building. It is a raw fact that this can be considered a basic necessity, but is becoming increasingly difficult for many to achieve not only because of the cost of housing, but the cost of living. For others, it may also limit investment opportunities and if it results in a reduction in demand can have broader economic implications, including in the job market.

Despite this, rising minimum performance requirements are not identified as the principal cause of increases in housing costs. This may vary according to the measure, the scope of any stringency changes and the cumulative effect of multiple changes occurring at the same time. However, they remain a relatively modest part of the cost of a new building, as many of the features are necessities for which building codes are setting minimum standards.

In developed economies it is typically acknowledged that the largest contributor to the cost of building a new home is land value, which in turn will be influenced by land supply. Other contributors make for a complex mix, but include labor, materials, taxation, lending practices, interest rates, inflation and the like.

Impact analysis of comparable subjects, such as energy efficiency and accessibility standards have found that whilst the cost of building a home may increase, it would not be observable with all the other types of inputs, such as those cited above. Put another way, any percentage increase brought about by regulation applies on top of the last dollar of other inputs. In most cases this will represent less than a single digit cost in percentage terms, however, these are upfront and certain. Benefits that come well into the future are less certain and so are discounted.

The disconnect between upfront costs and future benefits often represents a problem in construction. For this reason, comparing direct benefits to direct costs is encouraged rather than as a percentage of median (or worse than average) prices. Nevertheless, actual impacts on affordability, for the reasons given, will likely be minimal, although this may prove difficult to demonstrate under the cloud of uncertainty brought about by working to future projections.

Housing affordability is a highly sensitive topic, so the extent to which building regulation can achieve its policy objectives whilst limiting an increase in the cost of housing will be important to the prospect of any measures being accepted. In the case of *building resilience*, there appears to be a range of views within industry for the consideration of appropriate measures to be employed, but there is likely to be a strong interest in their costs.

A longer-term outlook will be required to shift the focus from first cost to average annualized cost of ownership; tie resiliency to building lifecycle, mortgage length and insurance premiums/accessibility; and encourage innovation through risk-based performance targets. It is also necessary to protect those likely to be most exposed, not only directly to extreme weather events, but also the ability to afford secure shelter.

Wherever possible, new buildings should be designed to accommodate the climate conditions throughout their expected service life as upfront costs are typically less costly than retrofits. Some planned future retrofit (adaptive design) should also be considered.

It is also relevant to consider that most of the serious natural hazard damage and destruction to buildings occurs to residential buildings and often in locations where more disadvantaged members of society reside.[37] Whilst each individual loss may not have great significance to society, holistically, the impact to multiple individuals or families and the community (especially for jurisdictions that are largely residential) may collectively have great significance. This talks to the broader capacity of society to afford picking up the pieces, especially if governments are required to become insurers of last resort, which can often be the case following a significant natural hazard event.

Whilst cyclical in nature, the compounding effect of recovering from such events, both materially and psychologically, places an enormous burden on individuals and society as a whole. As with all disaster mitigation initiatives, investment up-front is intended to reduce these impacts at a future point, by lessening the toll on people and the costs involved in recovery.

Finally, it is also valid to note that there is nothing to prevent building owners going beyond the minimum requirements of building regulations, and in areas of higher climate risk this is to be encouraged.

Principle 9: Existing buildings

Principle: Identify strategies to encourage existing building owners to bring their buildings up to a higher standard of resilience for the types of future weather-related natural hazards they may experience based on their location and climate projections.

Building codes and standards are typically applied to new buildings and new building work, but they can also be adapted for use in existing buildings, which in the context of future climate, are likely to be more vulnerable, particularly if constructed prior to the adoption of any contemporary natural hazard standards.

[37] Eckstein, D., Künzel, V., and Schäfer, L. 2021.

Policies and incentives that target resiliency in the existing building stock are a big part of the equation. Subsidies and tax credits for physical improvements to buildings as well as to compensate volunteers for time spent undertaking neighborhood improvements were cited by a number of respondents to the second Global Resiliency Dialogue survey as strong drivers to encourage wide-scale resiliency improvements. Likewise, a whole-of-community approach to resiliency, utilization of resiliency rating systems and tying improved resiliency into correcting historical inequities and removing people from harm's way, are all potential pathways.

Incentives for adaptation need to be effectively aligned. While societal benefits are clear, the often-high costs of alterations to existing buildings for climate resilience are frequently borne by the owner, while the benefits may be seen by future owners or society in general. Due to the cost of significant repairs and retrofits, adaptation measures generally have a poor uptake despite their potential to lift the resale value of a property if located in an area exposed to natural hazard events. This assumes, however, that the consumer is knowledgeable enough to understand the need for and value of the adaptive measures in place, for which some form of rating scheme might be useful at point of sale.

To ensure success, retrofits are more likely to be effective if they are supported by incentive programs for voluntary action (by grants, tax credits, insurance programs) to help recover initial investments in risk mitigation for which benefits will accrue over the long term. Incentive programs could mitigate some of these costs and help meet the needs of exposed populations, who may disproportionally depend on inadequate or redundant systems, or are subject to the willingness of a property owner to invest.

To increase uptake, resilience retrofit programs could consider coupling with energy retrofit programs. One of the most widely applied programs for retrofits for disaster risk across Canada is basement flood protection, usually offered by municipal governments, which typically provide subsidies for households that have experienced or are at risk of basement flooding, or that contribute to basement flood risk through private-side contributions of inflow-infiltration.

In all but a very small number of cases, uptake of these programs is extremely low. Similar programs offered by insurance companies, where households are offered retrofit funding following a flood claim, also experience low uptake. Whilst there is limited data to explain the low participation rate, it is potentially due to a number of factors, including a limited understanding by the public of low probability, high consequence events, ability to afford involvement, hurdles associated with applying, or the possibility that a basement is being rented to help pay the mortgage.

There are examples where access to higher levels of funding or other support mechanisms for resilient assets can also drive adoption. Germany's "100,000 roofs" program demonstrates the efficacy of funding support for resilient assets.[38] The program aims to promote the use of solar water heating collector systems by paying the capital cost of the units. It is a huge yearly investment since starting in the 1980's. It has created both industry capacity (manufacture, installation, repair, maintenance, architectural integration, etc.), and acceptance and awareness by homeowners who are now increasingly choosing it as a mainstream solution.

Mandatory disclosure of a building's exposure to natural hazards at time of sale already operate in some jurisdictions, such as property transfer certificates that identify flood and wildfire prone areas. As with programs for other initiatives to upgrade buildings, such as energy efficiency, a minimum level of improvement could be required again at time of sale, however, the feasibility of this would be highly dependent upon the age and condition of a building.

Supporting the home building industry in the development of strategies to market resilience strategies can complement other non-regulatory options, such as the development of codes/guidelines for voluntary application.

Principle10: Building maintenance

Principle: Encourage property owners to engage in the need for planned periodic and specified maintenance of their buildings and promote essential resilience features embedded within buildings to ensure their ongoing performance.

As is the case with ensuring compliance with the codes and standards at the time of construction, adhering to periodic and specified maintenance of buildings and the essential systems and products embedded in them is essential to their ongoing performance.

As buildings age, the issue becomes more one of maintenance than the initial design life. Routine renewals and maintenance of key elements will dictate actual service life, although the frequency will not always be clear other than where regulated or required to retain warranty continuity. This has two aspects:

1. In theory, carefully planned design will allow systems to be replaced as necessary without having to deconstruct or demolish. With attention to future proofing of the building, buildings should last as per the content of Principle 6, durability.
2. In practice, it is unclear whether one can reasonably assume renovation and replacement of key elements over the lifespan of a building; for example, while various forms of cladding may have a 30-year lifespan, they may never be replaced after that period.

[38] International Energy Agency. 2012.

Often it is only critical life safety systems that are required to be periodically maintained by codes and/or regulations. With the increasing complexity and inter-dependency of buildings and systems within them, this approach warrants re-consideration. In the context of building resilience this could become a critical life safety feature, should an HVAC system for instance fail during an extreme heat event.

Linked to this topic, maintenance regimes have been seen as more a function of building manuals and manufacturers' specifications, irrespective of how integral they may be to the ongoing performance of a building. Having regard to the definition of building resilience, this approach would benefit from further consideration given the intent to maintain the level of performance at the time of construction over the proposed service life of the building.

It may be valuable, within industry, to promote the need for building manuals that include maintenance regimes for key features of a building's resilience as part of helping educate building owners and users on the critical function of some features of their building. Unlike the maintenance of cars, there appears to be a general ambivalence or appreciation amongst many about the need to maintain buildings, which will become more significant if they are to include more sophisticated measures to reduce the impacts of extreme weather events.

The insurance industry can also play an important role in promoting the significance of maintaining critical features of a building and link this to premiums as a way of incentivizing this mindset. Emergency service authorities and not-for profit organizations can likewise run campaigns in the same way they do to remind people to replace batteries in their smoke alarms and maintain swimming pool fences.

Principle11: Compliance

Principle: Effective regulatory systems will incorporate appropriate resources to properly enforce the building codes and standards, as well as promote an ethic of compliance.

The need to ensure 'good enforcement' of building codes is of great importance. Failure to correctly construct building features designed to minimize the impacts of extreme weather events can significantly compromise the effectiveness of those measures, putting the wellbeing of individuals within buildings and possibly others outside at risk. It will also undermine the effectiveness of the additional resilience features the building structure could be expected to benefit from. Ultimately the consumer pays, whether this be directly, through insurance or government.

A useful example is where roof ties for a building designed to take additional wind loads in extreme wind areas are not installed in accordance with technical specifications. The result is the potential for all or parts of the roof to become fast moving projectiles that injure people, compromise other buildings and expose the building from which they originate to significant damage (and possibly to a level rendering the building redundant).

If compliance with the building codes and standards is not properly enforced there is the potential for global industry to operate at a low standard, in part for some to remain cost competitive and in part because noncompliance becomes accepted practice. This can drive good operators out of the market, further exposing consumers to bad practice and compromised assets.

Effective legislative frameworks and resources are necessary to provide practical tools for regulators to employ and help drive a culture of compliance within industry. Auditing and enforcement of the measures established to achieve improved *building resilience* will optimize their ability to reduce the risk they are attempting to address. This part of the regulatory system also needs to be designed to be efficient in order to reduce additional effort for the auditors.

Whilst not a function of building codes and technical construction standards, allotment level resilience will also contribute to the resilience of a building, such as site grading to reduce flooding and site clearance to reduce fire spread. Features such as these will typically be the subject of compliance under separate regulatory regimes. Being cognizant of such features is consistent with the Guideline's earlier recognition of a holistic approach to include matters that operate beyond building regulation.

Principle 12: Implementation

Principle: Complement any regulatory measures to improve compliance and support technical solutions with a wide range of education and practitioner capacity building tools.

Implementation will require significant investment in capacity building to increase understanding of the potential impacts of future climate scenarios and the utility of practical measures to help improve the resilience of buildings. It can be anticipated that some of the potential changes will require re-training and awareness raising amongst practitioners to ensure that installation is conducted correctly and effectively. This information ideally needs to come from a reliable and trusted source, such as professional industry associations, insurance agencies, local government, contractors and social networks (e.g., neighbours, family).

Education programs are needed to assist developers, builders and homeowners understand climate risk and potential actions to take. Bringing in trades to the resilience discussion (including potentially orienting economic incentives directly to them rather than homeowners) and better understanding of household behaviour (e.g., through behavioural economics) are required for these solutions to be useful. For instance, understanding by the trades of reasons for having different nail spacing or angles in areas of strong wind would lead to greater compliance. Where from a trades-persons point of view two nails are sufficient to hold a truss in place, but three are needed to prevent uplift in strong winds, the level of compliance will increase if they understand why.

Easily accessible guidelines for different audiences, clear messaging, robust guidance and strong imagery/interactive maps showing where/how climates and risk will change in locations over time will be beneficial and help simplify why and how the science is translated into building code provisions.

Capacity building may be supported by behavioural research, to provide insight into measures that will trigger uptake and can also proceed in conjunction with incentive programs.

The design of programs themselves represents an important part of capacity building. By way of example, this could include a program for installers/contractors to promote resilient practices during key windows of opportunity (basement flood protection when basements are finished, high wind/hail resistant roof covers when roofs are re-shingled). Canada has recently launched the Program of Applied Research on Climate Action in Canada (PARCA Canada) to apply behavioural science insights and methods with robust policy analysis to promote climate action.[39]

Capacity building is also critical to improve the ability for decision-making amid deep uncertainty. A wider understanding of the latest risk assessment methodologies and adaptation approaches would enhance the ability to utilize data that may not be in a format upon which cost-effective decisions can be made. In particular, outreach and education of technical committees regarding climate science and the role of buildings in mitigating risk from extreme weather events is essential, as they will be tasked with the review of resilience-oriented code change requests.

Other tools for consideration include the following:

- Targeted materials for incorporation into relevant training and educational practices/courses for the building and construction industry, especially where revisions to codes are concerned. In situations where modelling features prominently, open access data to help with modelling will be important, particularly for designers and where unique solutions may be necessary.
- Suitable and updated information should be delivered to communities through appropriate channels continuously. Clear and consistent language is needed and building capacity for solutions and ways to address, encourage and incentivize innovative solutions. The use of case studies to provide practical examples of changes and impacts will be important to help people think through decisions.
- In tandem with other measures, include improvements to professional development that provide education for 'building industry champions' to help them understand codes and standards to a level where they can be easily communicated to laypeople. Champions may include builders, department of fire and emergency services staff, local government staff, architects, designers, building consultants, etc.
- Identify early adopters of new measures, which in some cases will be from voluntary market leaders. Dissemination of lessons learned through case studies will be an important component of driving effective innovation and understanding unique scenarios.
- Financial incentives to assist building owners to retrofit existing buildings and design more resilient new buildings have a role. The availability (or lack of) insurance cover and the price of premiums is an effective way of communicating risk to communities.
- In particular, visualization tools (like energy modelling) and interactive, web-based tools would be most useful. Insurance industry modelling and future-casting information should be made available to support efforts in communicating code development and for public information.

Principle 13: Monitor and evaluate

Principle: Routinely monitor the need to maintain the currency of building codes and standards in response to updated climate science and projections.

Monitoring will be necessary to confirm predicted climate changes and their evolution, and ensure the technical solutions incorporated into codes are effective. This will grow the body of knowledge, which should be shared and assessed to determine if further change is appropriate. To do this, it will be important to establish key performance indicators across several assessment criteria to help determine the adequacy of the measures and appropriate intervals for their review given the non-stationary nature of the subject.

[39] Government of Canada. 2022.

Maintaining currency with updates to the science and climate projections will be a key role in monitoring the need for any ongoing changes to codes and standards, noting this will only affect new building stock going forward. Two approaches could be considered for this purpose. One is reaching a pre-determined threshold of damage or hazard severity as an informing tool for decisions. This, however, would establish a reactive approach and be inconsistent with the definition for *building resilience*, which promotes intervention using predictive modelling.

The other approach is one of continuous improvement, which may be less threatening as it is incremental, practical and reflects a natural evolution of knowledge and expertise. This could be tied to the availability of new climate data studies, a new scientific consensus around future climate data, or be based on a pre-established trigger. Alternatively, the climate data in codes could be updated as the codes are reviewed on a regular basis.

Another possibility would be to adopt a more fluid method, whereby changes to the level of risk prompt an assessment of the range of response options that may include adjustments in the code/regulatory regime. This would respond to concerns that good initiatives cease or are not fully implemented due to excessive targets, which may seem achievable at the time of adoption. Conversely, improvement may cease once a target (that did not stretch enough) has been achieved. Such a method would require a potentially more agile approach than codes are typically able to accommodate, given the processes they are required to adhere to as part of good regulatory practice and jurisdictional approval.

Given the non-stationary and unknown nature of future climate and associated natural hazards, monitoring needs to be a central feature in evaluating the performance of industry in the adoption and compliant application of the regulated measures, as well as the success in implementing aspects of other principles identified in the Guidelines, such as capacity building and engagement. This process of continuous improvement, which involves monitoring the effectiveness of the technical construction standards, is therefore the favored approach.

There is also a balance to be struck between the quality and granularity of information, and difficulty and cost of collecting it. This is likely to remain an open question until a better understanding of the magnitude of projected climate change relative to extremes already included in current design processes is achieved.

This comes back to the point of codes and standards being fit for purpose, which as with other topics they cover, requires a level of on-going monitoring to assess the adequacy of their performance against several potential criteria, not the least of which being an improved level of *building resilience*.

Another role of monitoring is to understand whether the regulation is meeting societal expectations, although in the context of future climate, the purpose is to get ahead of the curve and not await the consequences of predicted extreme weather events.

Some would point to several recent events as a reliable indicator of the need to act now, with so-called ‘unprecedented’ events occurring around the globe, exampled by:

- Canada, the second coldest country in the world, experienced temperatures of close to 50 degrees Celsius, 24 degrees above average in 2021, resulting in 595 heat-related deaths [40]
- In the summer of 2019/2020, Australia experienced the most widespread and destructive bushfires on record, destroying upwards of 20% of the nation’s forests [41]
- Apart from recording 688 fatalities and $145 billion in damage from natural hazard events in the United States in 2021, many of the events took place late in the year, with tornadoes atypically experienced in December [42]
- Parts of New Zealand recorded their largest ever recorded flood in 2021, recording more than 300 millimeters of rain in 48 hours in some places [43]

The Global Resiliency Dialogue, serving as a forum to share information and exchange ideas, is a practical demonstration of creating an environment for continuous improvement. Within their respective jurisdictions, examples exist of *building resilience* responses being employed in the face of extreme weather events. These function as case studies that contain information others can use and provide input to the principles featured in the Guidelines. The case studies can be found in the **Appendix.**

Evaluation is an important part of an effective regulatory system so that it establishes a feedback loop for continuous improvement and measure key performance indicators.

[40] Government of Canada. 2021.
[41] Forex Capital Markets Australia. 2020.
[42] Smith, A.B. 2022.
[43] Davies, R. 2021.

Principle 14: Engagement

Principle: A clear and uncomplicated communication strategy that embraces and simplifies risk-based information; uses a common, credible and consistent set of evidence; and caters for the many and varied views of those with an interest in this subject.

As with anything to do with climate change, there are a vast number of groups directly involved with or interested in participating in the process of transitioning to a more resilient built environment. These are represented at the international, national and local levels, and can be loosely categorized according to Figure 9:

Figure 9

United Nations	Building code authoring organizations	Relevant not-for-profit organizations	Inspection and compliance providers
World Bank and International Monetary Fund	Building code officials	Community service providers	Developers
International Finance Corporation	Standards development organizations	Insurers/reinsurers	Facility managers and owners' corporations
National, state/provincial, local and tribal governments	Land use planning agencies	Financial institutions	Advocacy/lobby groups
Disaster mitigation and relief agencies	Emergency service authorities	Relevant membership associations of design professionals	Academics
Environment protection agencies	Research bodies, science establishments and universities	Relevant industry organizations	Media
Climate emissions mitigation and energy efficiency agencies	Aid agencies	Manufacturers	General public, including Indigenous communities

Engagement with such a broad set of interests on a topic that can be divisive, difficult to understand and involves approaches that are not mainstream will require careful stewardship and patience, even though there is a critical time element attached to the work.

Having a clear communication strategy that both embraces and simplifies risk-based information is essential. Using a common, credible and consistent set of facts from a unified group of climate and building scientists, presented in clear language, will prove very useful to policymakers.

Equally critical is for any messaging to be completely devoid of the politicization of climate science, meeting people where they are and demonstrating respect for differences of opinion, while acknowledging the scientific evidence. Reaching agreement on the point that climate change is occurring is merely the first stage, and a dialogue needs to be created with the understanding that some people believe the harm caused by 'a little' warming is minimal, while others predict dire consequences. In this circumstance, case studies and lessons learned can be an effective tool in illustrating possible scenarios and leading to a constructive discussion about potential solutions.

Given the diversity of interests and the various reasons for engaging with different stakeholder groups, the engagement strategy will need to be very sophisticated. For instance, what is needed from scientists to assist policymakers will be different than the discussion with technical experts about the drafting of suitable provisions and different again to the consultation with the broader community in helping to better understand levels of acceptable risk, whilst managing what may be unrealistic expectations in respect to what building codes and standards can provide for.

Management of expectations will vary across the different groups as their interests are not consistent. This will also potentially change over time, given it will be an exercise in translating the science into technical regulation and allowing it to evolve as knowledge and experience grow. Communication at a local level using a simple message of science and risk, how they can best be tackled and what the benefit is to individuals in having them addressed, is likely to be most successful in helping manage expectations. This can also raise awareness amongst those groups most disengaged from the specific nature of the subject, which may include community organizations, builders and other trades.

Other aspects of an engagement strategy that can speak to many of the barriers identified earlier are to promote a forward-looking mentality that identifies both latent and future conditions; placing building codes within the context of the broader tiers of resilience and homes within the context of community resiliency; and engage financial/insurance/construction sectors to establish a complementary view – alignment of financing streams to mitigate risk.

Providing code officials with the right tools to communicate the importance of resilience is also important as they are often the interface with owners and designers and at the forefront of explaining regulations. They need to have a proper understanding of the risks and mitigation strategies. Shifting the narrative of potential risk measures would be an effective starting point, as it is difficult for people to grasp probability of occurrence in 100 or 500 years, and effectively apply that to the risk level that they may face within, for instance, the length of their mortgage, length of the expected useful life of their building, or their own life span.

The key aims of any engagement around *building resilience* will be to consult on the development of technical code provisions and standards. This will involve accessing the technical expertise of building scientists and industry professionals to examine their workability and prospect of achieving the desired outcome. Consultation on impact assessment will form part of this and it will be important to obtain critical data and information from a range of stakeholder sources as to the costs and benefits of various options.

This part of the process will need to follow a more structured approach to engagement, much of which may be statutory, but can also accommodate more flexible opportunities for those who are unfamiliar to become involved. Given the large number and varied views of those with an interest in this subject, it is important to employ approaches that promote the opportunity for equitable outcomes achieved through enabling all voices to be heard.

An engagement strategy could also be coupled with incentives and disincentives to educate buyers about future behaviours that demand resilience in their investments and reject those that are not adequately resilient.

Principle 15: Emissions reductions

Principle: Building code development can make an important contribution to mitigating the causes of climate change with subsequent long-term benefits for building resilience.

Whilst the Guidelines are directed at *building resilience* and therefore adaptation of buildings to future climate, it is equally important to continue efforts to mitigate the causes of climate change. These actions also form a realistic part of a comprehensive approach to resilience.

The latent effects of GHG emissions already in the atmosphere will continue to change the climate over many decades irrespective of future mitigation actions, which necessitates action on adaptation. Addressing climate change mitigation will over the longer term, however, improve the prospect that adaptation measures can be reasonably effective.

It is pertinent to note that it is impractical to address all of the effects global warming may have on buildings through relying on resilience alone. Therefore, there will be diminishing returns from investing in resilient buildings if international efforts to mitigate the causes of climate change, for which improving the energy efficiency of buildings is an important and achievable objective, are not acted upon.[44] In other words, if efforts to stabilize global warming are unable to keep global temperature increases to below 2 degrees Celsius, then the capacity to manage the impacts on buildings through resilience features will be significantly compounded.

Climate change mitigation measures that reduce GHG emissions are distinct from climate event impact mitigation measures, which can be considered to be treating the symptom rather than the cause. Emissions reduction should be a principle for *building resilience* not only because of the nexus described above, but because some climate change mitigation measures have a direct connection to extreme weather events.

A case in point is having more energy efficient buildings and construction, which the World Green Building Council estimates accounts for 39% of all carbon emissions in the world (28% of which is related to operational carbon and 11% from embodied carbon).[45] Whilst it is important to resolve issues of ventilation to mitigate the potential effects of condensation and occupant comfort, more energy efficient buildings can both reduce GHG emissions and provide improved thermal comfort for occupants of buildings in the event of extreme heat or cold.

Climate resilient construction has also been shown to contribute to a reduction in lifetime GHG emissions, creating a symbiotic relationship between actions to improve building resilience and mitigation.[46] A possible extension of this discussion will be consideration of the balance between a building's service life and overall embodied carbon.

[44] Saberi, O. and Beykan, N. 2022.

[45] Oosterveer, P. 2021.

[46] National Research Council Canada Construction Research Centre. 2022.

CONCLUSION

The Global Building Resilience Guidelines represent the culmination of more than three years of work by the Global Resiliency Dialogue with the support of a diverse range of organizations, the input of many individuals and the research findings of the some of the most reputable scientific bodies.

With the aim of developing a set of principles that can be used to help inform the development of building codes and standards for the construction of buildings to better withstand today's and future extreme weather conditions influenced by the effects of climate change, the Guidelines identify a number of important matters for deliberation.

Some of these considerations draw parallels with the work of others in looking to address the impacts of climate change and how to provide for a better level of resilience. The Guidelines expand on this theme with the express intent to consider the role of buildings in helping individuals and communities to withstand and recover from a weather-related natural hazard event, noting that in all likelihood there will be residual impacts if the intensity and scale of recent incidents are representative of future events.

Building codes and standards shape much of what is built by setting minimum requirements. Whilst these can be exceeded and there will be different construction methods employed to satisfy the requirements, the types of buildings people occupy for all manner of activities are intended to serve one primary purpose, occupant health and safety.

Building resilience, which the Guidelines attempt to define and distinguish from other interpretations of resilience, acknowledges that whilst the primary purpose of codes and standards should remain, the objective of ensuring the on-going performance of a building's most basic attributes is going to be an important consideration in helping individuals and communities to better recover from more extreme weather events, and reduce the broader cost burden placed upon society.

The principles point to the critical importance science will play in helping determine future climate scenarios, how to design for them and how building codes and standards will accommodate contemporary responses. Fundamental to this equation is engaging in the use of predictive methods of evaluating minimum requirements and applying these at a relatively granular level to avoid a 'one-size' fits all approach.

The Guidelines attempt to assist those who are involved and have an interest in these arrangements, by exploring the likely approaches needed to make informed decisions and effective regulation.

EXTREME WIND EVENTS: CASE STUDIES FROM THE UNITED STATES

In the U.S., extreme wind events typically take the form of hurricanes (cyclones), tornadoes and severe storms (including derechos). Many of these events also include precipitation related impacts. The case studies below capture how two communities adjusted their building codes or design criteria in response to a catastrophic event or series of events, recognizing increasing risks into the future.

Moore, Oklahoma: Tornadoes

Introduction

Although tornadoes have not yet been assessed to have a direct link to climate change, the growing variability, seasonality, intensity and geographic distribution of events are a cause for concern in the United States.[47] After experiencing three disastrous tornadoes with an intensity of EF-4 (on the Enhanced Fujita scale) or greater over a 14-year span, the City of Moore, Oklahoma recognized the need to improve its building code to mitigate their risk to the effects of severe wind and tornado events.

Hazard Event

The City of Moore, Oklahoma experienced three catastrophic tornado events from 1999 to 2013. On May 20, 2013, the City of Moore experienced an EF-5 tornado, the most extreme and destructive tornado of the three. The tornado was the third costliest tornado in U.S. history,[48] resulting in $2 billion in damages, 24 fatalities including seven children in an elementary school, over 200 additional injuries and 300 destroyed homes. The casualties at the Plaza Towers Elementary School were a result of the collapse of the walls in the masonry hallway.[49] The prior two tornadoes, an F-5 event in 1999 and EF-4 event in 2010, resulted in 38 total deaths (36 in 1999 and two in 2010), the destruction of numerous homes and infrastructure (1,800 homes in 1999), and significant economic losses ($1 billion in damages during 1999).

Responding with Resilience

Following the destructive 2013 tornado, the City of Moore responded by becoming the first municipality in Oklahoma to adopt stringent wind standards into its residential building code. In 2014, Moore's city council voted to adopt a series of amendments to its residential building code, ultimately adopting the strongest building code for wind hazards in the nation.[50] The code provisions provide updated requirements to mitigate damage caused by tornadoes capable of generating extreme winds up to 135 miles per hour (mph)—equivalent to a storm intensity of EF-2. The updated residential code requirements included narrowing spacing of roof joists, the use of oriented strand board to strengthen exterior sheathing, wind rated garage doors, and hurricane straps to secure the roof to the exterior walls.

Outcomes

The City adopted the enhanced Moore building code in recognition that their current codes were not sufficient to withstand future extreme tornado events, adopting requirements that increased the wind design standard from 90 to 135 mph. Despite concerns from the Moore Association of Home Builders that such provisions would dramatically increase construction costs, studies following the updates found that the building code amendments had minimal effect on price per square foot of new home, sale price or volume of residential construction.[51]

New York City: Hurricane and Extreme Wind Events

Introduction

The growing intensity and distribution of catastrophic hurricanes are linked to warmer ocean temperatures and sea level rise which are attributed to climate change.[52] With growing intensity of cyclone wind velocities and rainfall, communities located in coastal regions face greater risk to the associated impacts. Following Superstorm Sandy in 2012, which caused catastrophic damage from intense storm surge, wind and flooding, New York City (NYC) developed and implemented a multi-hazard approach to better prepare for future extreme weather events.

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47 Henson, B. 2021.

48 National Oceanic and Atmospheric Administration. 2015.

49 Kuligowski, E.D., Phan, L., Levitan, M.L., and Jorgensen, D.P. 2013.

50 Simmons, K.M. and Kovacs, P. 2018.

51 ibid.

52 Center for Climate and Energy Solutions. n.d.

Hazard Event

On October 29, 2012, Superstorm Sandy hit New York City and surrounding communities. Extreme sustained winds in excess of 80 mph, and intense storm surge from the hurricane destroyed roughly 300 homes, left hundreds of thousands of New Yorkers without power, damaged critical public and private infrastructure, and left many people vulnerable with limited access to food, drinking water, healthcare, and other critical services. Superstorm Sandy resulted in 44 deaths, $19 billion in damages and economic downturn, a total of 51 square miles of flooded land, and damage to over 69,000 residential units leaving thousands of residents temporarily displaced.[53]

Responding with Resilience

In 2014, the New York City Building Code was updated from the 2008 version to reinforce the City's push towards resilience resulting from lessons learned from Superstorm Sandy. "Appendix G: Flood-Resistant Construction" of the International Building Code was a major element of the 2014 code, which included increased freeboard requirements based on updated flood maps, prescribed design flood elevations, and requirements for dry and wet floodproofing strategies.[54] The updated NYC Building Code also referenced the American Society of Civil Engineers (ASCE) 24-2005, Flood-Resistant Design and Construction, as a compliance pathway for new construction, structural repairs and substantial improvements to existing buildings located in flood hazard areas—which meet or exceed the minimum requirements of the National Flood Insurance Program requirements. The 2014 NYC Building Code also included minimum elevation requirements and was complimented by the enactment of various local laws including Local Law 101-2013 which amended NYC Building and Mechanical Codes to include requirements to prevent wind damage to certain buildings and systems.

Outcomes

New York City acknowledged the importance of building codes to increase coastal resilience, identifying code requirements as an effective tool for preventing severe damage to buildings in response to extreme weather events. Newer buildings constructed to modern code requirements fared better during Superstorm Sandy, with 98% of buildings destroyed having been built before 1983.[55] Since Superstorm Sandy, building on lessons learned, NYC has continued their commitment to the adoption of modern building codes and standards to increase their resilience and response to hurricane events in the future. The City is now in the process of updating to a 2022 version of their Building Code modelled after the 2015 International Codes (I-Codes), with reference to some sections of the 2018 I-Codes, which will become effective in November 2022. The 2022 Building Code references ASCE 24-2014 for enhanced flood-resistant design and construction standards. New York will model their next subsequent Building Code on the 2021 I-Codes.

Incorporating Beyond Code Design

In 2008, the City formed the New York Panel on Climate Change (NPCC), made up of leading climate and social scientists, to provide regional climate change projections that inform the City's climate resiliency policies. In response to the anticipated increase in the intensity and severity of flooding, precipitation, and heat events over the 21st century, NYC developed the preliminary version of the Climate Resiliency Design Guidelines in 2017. The City's Climate Resiliency Design Guidelines were developed to provide step-by-step instructions to go beyond the existing building code and standards, by also looking to specific, forward-looking climate data for use in the design of City facilities.[56] NYC released version 4.0 of the Guidelines in the spring of 2021, which now includes reporting requirements.

Future versions of the Guidelines, in coordination with the NPCC, will explore additional climate stressors as science evolves. The Guidelines complement the use of historic data in existing codes and standards by providing a consistent methodology for engineers, architects, landscape architects, and planners to design facilities that are resilient to changing climate conditions.

The City of Boston, Massachusetts (Land-use Planning and Building)

Boston's climate change resilience plan[57] outlines a key strategy for dealing with future flooding. Strategy 9 is focused on updating zoning and building regulations to support climate readiness. The current regulations that govern development in Boston do not have specific requirements for preparing for future climate conditions. In some cases, they may even pose obstacles to doing so. For example, within state building code regulations, many buildings would need to elevate their first floors and mechanical systems. However, regulatory limits on height and bulk often discourage such elevations.

Strategy 9 seeks to add to existing zoning and building requirements and require relevant authorities, such as the Boston Planning and Development Agency, to propose land-use and other regulations that ensure new development is ready for future climate conditions. For example, current regulations foster a site-scale approach to climate readiness. Within the City of Boston, while individual new and renovated buildings have some requirements to build to certain climate-ready

[53] New York City. n.d.

[54] Hartman, K.J., and Stieve, D.R. 2018.

[55] New York City Department of City Planning. 2012.

[56] New York City Mayor's Office of Resilience. 2020.

[57] City of Boston. 2016.

standards, there are no regulatory mechanisms to build in a way that would provide broader district-scale flood risk reduction and address the impact of individual retrofits and adaptation projects on overall flood risk and urban design.

Regulations also do not protect the beneficial functions of storm damage prevention and flood control provided by the coastal floodplain. Further, the strategy outlines that the City of Boston should advocate for changes to the Massachusetts Building Code and explore measures that increase climate-ready retrofits in existing buildings.

The initiatives within Strategy 9 follow three basic principles:

- The City should prioritize areas in which it has independent authority. The City of Boston as a local authority has control over zoning laws and can actively amend them, but does not have control over the building code, which is a state-level law. Therefore, Strategy 9 seeks to work with the state to address climate readiness.
- The City is the ultimate long-term investor in all local properties. Individual and commercial and institutional property owners often only have a limited time horizon for owning certain properties and therefore may not want to invest in long-term solutions that address future climate risk or interventions where benefits accrue to future owners.
- The Climate Ready Boston strategy outlines that the City of Boston has a moral and financial interest in making sure that buildings remain safe and maintain their value for future generations.

MANAGING MULTI-HAZARD RISK FROM FLOODING: CASE STUDY FROM NEW ZEALAND

New Zealand is Highly Vulnerable to Natural Hazards

New Zealand's geography and location make it prone to a range of natural hazards, including earthquakes, volcanoes, erosion, landslides and extreme weather events. Floods are one of New Zealand's most frequent emergency events, earthquakes and tsunamis are less common but have the potential for greater damage and disruption. It can be difficult to translate the concepts of risk and data relating to natural hazards into proportionate responses to mitigate these. Lack of available and usable data means development decisions continue to be made that increase the risks faced, especially in land-use planning. This creates new risk, which will ultimately lead to unnecessary future economic and social losses.

Strong building regulation and governance is one of the most effective approaches to managing natural hazard risks. It, along with land-use planning, insurance, and resilient infrastructure, are significant drivers and determinants of how communities and the built environment come through natural hazard events.

Multi-hazard Risks Following the Canterbury Earthquake Sequence

In 2010-2011, a series of earthquakes centered around the City of Christchurch, in Canterbury, New Zealand highlighted the potential for moderate magnitude (Mw 6 – 7) earthquakes to cause major topographic changes that influence multi-hazard risks in coastal settings. The earthquake sequence caused widespread ground shaking, fault rupture (warping of the land along a fault where it meets the ground surface), liquefaction (temporary loss of strength of ground with high water content during shaking, causing damage to structures it supports) and landslides.

The 22 February 2011 earthquake resulted in 185 people losing their lives and many more injured. The Canterbury Earthquakes changed public perceptions of natural hazards and highlighted the vulnerability of buildings to seismic activity, including the multi-hazard events that followed the earthquakes. Statistics obtained from Insurance Council NZ indicates the Canterbury rebuild involved 650,000 insurance claims with a total rebuild amount of ~NZ$31B[58] (~US$19B). This makes it one of the world's largest disasters on record.

Some examples of multi-hazard events that happened following the Canterbury earthquake sequence include:

1. land damage (e.g., lowering of the ground surface) resulting from seismic activity has increased the groundwater level, leading to a significant increase in future flood risk (fluvial, pluvial and coastal);
2. sea-level rise hampering drainage of low-lying areas, raising groundwater levels and thereby increasing flood risk. Future accelerated rises in groundwater levels will likely contribute to an increase in the area susceptible to liquefaction;
3. climate change will result in an increase in the intensity of extreme rainfall events, increasing risks from flooding, coastal inundation and coastal erosion.

The experience from the Canterbury Earthquake sequence has led to the recognition that a coordinated and holistic approach is required to address the increasing risk from multi-hazard events.

[58] Insurance Council of New Zealand. 2021.

The Role of the Built Environment in Natural Hazard Risk Management

Hazard risk management in New Zealand is currently managed across three key pieces of legislation: the Resource Management Act 1991 (RMA); the Local Government Act 2002 (LGA); and the Building Act 2004. From these three frameworks, governance decisions are made to reduce natural hazard risks for communities, businesses, and individuals. Regulation of the built environment is a significant tool to reduce risks from natural hazards in New Zealand.

Recent Changes to Building Code Documents

New Zealand has earthquake hazards that pose a well-understood and immediate threat to the built environment, but they may also trigger other hazards, such as liquefaction, landslides and flooding. The risk from these hazards will be exacerbated by climate change due to the prospect of more frequent high intensity rainfall events.

Under powers conferred by the Building Act 2004, changes were made to Building Code compliance documents in 2019[59] which required regional Building Consent Authorities to conduct a hazard mapping exercise as part of a hazard identification process, with specific rules that limit development in higher risk areas. These changes have resulted in the following outcomes:

1. Liquefaction hazard maps and hazard management maps are required throughout New Zealand;
2. Key geotechnical information relevant for future land development is collected and collated by Building Consent Authorities; and
3. Safe and more resilient foundations are required for buildings on liquefaction prone ground.

These changes mean that from 2019, new buildings throughout New Zealand require robust foundations if they are shown to be constructed on liquefaction prone ground. This change has given more clarity to local councils, engineers and developers, resulting in safer and more resilient buildings.

Applying the Lessons Learned from Seismic Hazard to Flood Hazard

Having witnessed the benefits of considering multi-hazard risks following the Canterbury Earthquake sequence, a multi-hazard assessment approach for long-term planning is being undertaken in Christchurch to inform Christchurch City Council's decision-making[60] on future infrastructure planning and construction. Initially, the approach had focused solely on responding to fluvial and pluvial flooding, historically the most frequent hazard for this city, but now the approach considers a range of hazards holistically, through a 'multi-hazard' lens. This promotes effective, long-term sustainable interventions to reduce risk, and the approach is being used to answer the question: How do we make decisions about flood management in a multi-hazard environment? A multi-hazard assessment of flood response options, including various defenses, will help inform decisions on the most appropriate way to manage the city's development in flood prone areas now and in the future, given the anticipated effects of climate change on these risks.

EXTREME HEAT: CASE STUDY FROM AUSTRALIA

Introduction

Australia is a large land mass, with varied climate, and susceptible to a range of extreme weather events. The National Construction Code (NCC) applies 9 climate zones across the continent ranging from alpine areas which experience cold, snowy winters and cool summers, to hot humid areas with warm dry winters and monsoonal, humid and hot summers. Climate change means summers in Australia are getting hotter. Heatwaves (defined in Australia as being three or more days in a row when both daytime and night-time temperatures are unusually high) are more frequent and severe.

Response by the Building Code of Australia

Sustainability is an objective of the NCC, along with an express aim of reducing GHG emissions. The NCC includes performance requirements for energy efficiency, including some applicable to building fabric to reduce the need for mechanical heating and cooling of commercial and residential buildings. The standard of expected performance has been progressively raised as a way to allow the market to adjust; as well as to increase efficiency and resilience of buildings in response to averaged and extreme temperature.

The most common way for residential dwellings to comply with the energy efficiency performance requirements in the NCC is using the Nationwide Home Energy Rating Scheme (NatHERS)[61] . In 2020-2021, around 94% of building approvals were progressed using NatHERS.[62] Under the rating scheme, a 10-star NatHERS dwelling would need virtually no heating or cooling to maintain comfortable indoor temperatures, whereas a 0-star rating would mean the dwelling provides little or no resistance to external temperatures.

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[59] New Zealand Ministry of Business, Innovation & Employment. 2021a.

[60] Todd, D., Moody, L., Cobby, D., Hart D.E., Hawke K., Purton K., and Murphy A. 2017.

[61] NatHERS is run by the Federal Department of Industry Energy Resources and Science, in collaboration with the Commonwealth Science and Industry Research Organisation (CSIRO).

[62] Commonwealth of Australia. n.d.

The thermal performance of building designs are assessed under NatHERS by looking at construction type, insulation, orientation and air flow, as well as glazing placement, composition, size and external shading. NatHERS software and zone-specific climate files are used to estimate the performance of the design. The rating is derived from the expected energy consumption.

Prior to 2019, NatHERS imposed only a total thermal load intensity limit, based on energy use. This allowed imbalanced design where a building could be over-optimised for the dominant season, causing excess energy use in the non-dominant season. As a consequence, poorly optimised buildings used excessive energy to maintain comfortable temperatures during extreme heat or cold events. In 2019 the NCC introduced additional heating and cooling load limits to address unbalanced thermal performance in buildings. These new load limits were set to address the worst 5% of performing (i.e. highest) cooling and heating loads for compliant buildings in each NCC climate zone.

Outcomes

Energy efficiency provisions were introduced into Australian building codes in the early 2000s. The minimum required rating was increased to 5 stars in 2005. A study on heat stress and energy efficiency found risks of heat stress during a heatwave is 50% lower in a 5.4 star-rated house than in a 0.9 star-rated house.[63] A 2016 study of houses in Victoria indicated that for the representative sample considered, on average those constructed prior to 2005 achieved less than 1.6 stars.[64] This demonstrates a significant improvement to the energy efficiency and thermal performance of houses since the inception of these Code provisions.

Consistent with the original plan, in 2010 the minimum required rating was again increased; this time most dwellings needed to achieve a minimum of 6 stars. For most NCC climate zones, the 2019 introduction of separate heating and cooling load limits achieved more balanced energy use and thermal performance across seasons. Some jurisdictions have also introduced additional provisions for solar panels and water tanks. Further increases in stringency of the NCC energy efficiency provisions are expected into the future.

Including thermal performance as part of energy efficiency and sustainability provisions ensures that measures to adapt and increase thermal performance do not also increase GHG emissions.

Better Practices Beyond Minimum Code Design

The NCC sets the minimum requirements that must be met to demonstrate compliance as required by Australia's State and Territory legislation. Building owners may choose to design their buildings to voluntarily exceed these regulatory minimum requirements to achieve improved performance.

The NatHERS rating scheme has allowed people to measure performance and choose to go beyond the minimum, voluntarily designing 7 star, 8 star or greater dwellings. For example, in 2021 just under 20% of dwelling designs were already meeting or exceeding the 7 star requirement .[65]

At the community level, sustainable developments combining planning, infrastructure and building design are also progressing. Integrated sustainable design can demonstrate improved energy efficiency and in parallel, increased resilience to extreme heat. Notable projects underway at the time of writing (2022) include Witchcliffe Ecovillage in Western Australia, Ginninderry Development in the Australian Capital Territory, and The Cape in Victoria.

BUILDING & INFRASTRUCTURE RESLIENCE, INCLUDING IN THE WUI: CASE STUDIES FROM CANADA

The National Research Council of Canada (NRC), with funding from Infrastructure Canada, has been working since 2016 to integrate resilience to climate change and extreme weather into guidance, standards, and codes for Canada's infrastructure and buildings. The following two case studies demonstrate how the NRC successfully mobilized knowledge and stakeholders across disciplines to address known resilience gaps in Canada's construction sector.

National Guide for Wildland-Urban Interface Fires

Introduction

Wildfire resilience for buildings was one of the pressing needs identified in a gap analysis conducted by Canada's Climate Resilient Buildings and Core Public Infrastructure initiative. In 2016, a wildfire swept through Fort McMurray, Alberta, destroying over 2,500 structures and forcing 90,000 people to evacuate. The resulting losses exceeded 9 billion Canadian dollars. The NRC began development of a National Guide for Wildland-Urban-Interface (WUI) Fires shortly after this record-breaking wildfire and due to the recent increase in frequency and severity of WUI fires in Canada.

[63] Alarm, M., Rajeev, P., Sanjayan, J., Zou, P.X.W., and Wilson, J. 2018.

[64] Sustainability Victoria. 2015.

[65] Australian Commonwealth Scientific and Industrial Research Organisation. n.d.

Guideline Development

The first step was to bring together knowledge and expertise across the country and internationally by establishing a Technical Committee of Wildfire Experts. The technical committee (TC) included representatives from federal, provincial and municipal governments, FireSmart Canada, insurance, codes and standards organizations, research bodies, professional associations (including firefighters and homebuilders), academics, and industry. Next, the NRC conducted a review of national and international guidance to produce a seed document as the basis for a new National Guide. The TC oversaw the general development of the guide, while task groups, under the oversight of the NRC and TC, led the drafting of specific chapters on: hazard and exposure, risk mitigation measures in the structure ignition zone, community planning and resources, and emergency planning and outreach. In parallel, research was conducted to inform wildfire hazard and risk prediction in a changing climate, and to improve test methods to evaluate and mitigate ignition in the WUI area due to embers, radiation, and direct flames. The NRC published the completed National Guide for Wildland-Urban Interface Fires in June 2021.[66]

Expected Impacts

To support adoption of the Guide, the NRC commissioned an impact analysis (costs and benefits) by the Institute for Catastrophic Loss Reduction.[67] The study looked at the capital and maintenance costs of moving from current construction practices to the practices recommended in the Guide. It also estimated ignition probability and avoided losses, including deaths, injuries, property loss, additional living expenses, indirect economic loss, insurance costs, instances of post-traumatic stress disorder, and some environmental costs. The study concluded that national use of the Guide would save up to $4 for every $1 invested, with new houses in high-hazard areas saving more than $30 for every $1 invested.

Roadmap Towards Uptake and Implementation

In 2021, a record-breaking heat wave and devastating wildfire destroyed over 90% of all structures in the village of Lytton, British Columbia. To build back better, the village is in the process of establishing new bylaws including a regulation based on the Guide. Work is now underway by the NRC to move the Guide through to standardization in partnership with a standards development organization. The NRC is also undertaking important policy discussions on the role of building codes in addressing wildfire resilience, within the suite of other policy instruments like urban planning and retrofit programs.

Future-Looking Climatic Design Data for Buildings and Bridges

Introduction

Current practice in the *National Building Code of Canada* is to design buildings based on past climate observations. In 2016, a gap analysis of current building codes under Canada's Climate Resilient Buildings and Core Public Infrastructure initiative identified the need to consider future climate change in the design of buildings. The analysis also found that many of the climatic design variables referenced in Canadian codes were out of date, and needed to be revised to include the most recent historical records. Some of these variables had not been updated since the 1970s.

Convening Engineers and Climate Scientists

To address this challenge, the NRC partnered with Environment and Climate Change Canada (ECCC) to update outdated historical climatic design data and to generate projected climatic design data for predicted future climates for the design of buildings and bridges. The NRC and ECCC brought together leading national and international experts in codes and climate science to develop methods to create new "future climatic design variables," leveraging the latest understanding about observed and projected changes in temperatures, precipitation, wind, and the cryosphere in Canada .[68]

Solution

Out of date historical variables were updated to reflect recent observations, up to 2018, in the 2019 edition of the Canadian Highway Bridge Design Code and the 2020 edition of the National Building Code of Canada.

Developing future climatic design variables required new methodologies. When considering the many design variables relevant to buildings and bridges, there are varying levels of confidence in future projections for a given level of global warming. This led to a multi-tiered approach. Tier 1 variables are suitable for design, with generally high or very high confidence (e.g. temperature-related variables). Tier 2 variables, with a medium confidence (e.g. rainfall-related variables), are best suited for risk assessment and cost-benefit analyses. Tier 3 variables, with a low or very low confidence in the future projections (e.g. humidity, wind, snow and ice), are best suited to explore the potential impacts in different scenarios.

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[66] Bénichou, N., Adelzadeh, M., Singh, J., Gomaa, I., Elsagan, N.. Kinateder, M., Ma, C., Gaur, A., Bwalya, A., and Sultan, M. 2021.

[67] Porter, K., Scawthorn, C., and Sandink, D. 2021.

[68] Bush, E. and Lemmen, D.S. (Eds.). 2019.

The climatic design variables are linked to degrees of global warming, rather than to emissions scenarios. This enables decision-makers, such as codes and standards committees, to design based on their adopted service-life and emissions scenario. The detailed methodological approach, and data for over 660 locations across Canada, is available in the 2020 publication *Climate-Resilient Buildings and Core Public Infrastructure: an assessment of the impact of climate change on climatic design data in Canada.*[69]

Supporting Adoption by Users, Codes and Standards

To enable users to access both historic and future climate data across Canada for the design of buildings and bridges, an interactive design value explorer was developed.[70] This was the first future-climatic design data set in Canada to consider wind, snow, and ice. As a result, the data has proven useful beyond the buildings and bridges sectors.

Future climate data is now under consideration by committees developing the next editions of Canadian codes including the National Building Code of Canada, the Canadian Highway Bridge Design Code, and standards including CSA S478 Durability in buildings. To support these committees in understanding and implementing the data, the NRC has planned assessments to quantify the impact of basing structural design of buildings on future snow and wind loads. Important policy discussion are also underway to support the transition from designing based on historic data towards designing based on the outputs of climate models, including defining a design service life for buildings and infrastructure and selecting an appropriate emissions scenario.

[69] Cannon, A.J., Jeong, D.I., Zhang, X., and Zwiers, F.W. 2020.

[70] Pacific Climate Impacts Consortium. 2022.

BIBLIOGRAPHY

Alarm, M., Rajeev, P., Sanjayan, J., Zou, P.X.W., and Wilson, J. 2018. "Mitigation of heat stress risks through building energy efficiency upgrade: a case study of Melbourne, Australia." *Australian Journal of Civil Engineering:* April 1, 2018. https://www.thefreelibrary.com/Mitigation+of+heat+stress+risks+through+building+energy+efficiency...-a0561598198.

Arias, P.A., N. Bellouin, E. Coppola, R.G., et. al. 2021. "Technical Summary. In Climate Change 2021: The Physical Science Basis." *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33–144. https://doi.org/10.1017/9781009157896.002.

Australian Building Codes Board. 2021. "Global Resiliency Dialogue Second Survey of Building Code Stakeholders – Australia: Delivering Climate Responsive Resilient Building Codes and Standards." *Global Resiliency Dialogue:* October 2021. https://www.iccsafe.org/wp-content/uploads/Global-Resiliency-Dialogue-Second-Survey-Report-Australia-03112021.pdf.

Australian Building Codes Board. 2002. "Guideline on Durability in Buildings." December 31, 2002. https://www.steel.org.au/resources/elibrary/library/guideline-on-durability-in-buildings/.

Australian Commonwealth Scientific and Industrial Research Organisation. n.d. "Energy Rating – National Overview." *Nationwide House Energy Rating Scheme, Australia:* Accessed March 24, 2022. https://ahd.csiro.au/dashboards/energy-rating/energy-rating-national-overview/.

Ayyub, B.M. (ed.). 2018. "Climate-Resilient Infrastructure: Adaptive Design and Risk Management." *American Society of Civil Engineers Committee on Adaptation to a Changing Climate:* October 2018. https://ascelibrary.org/doi/pdf/10.1061/9780784415191.fm.

Bénichou, N., Adelzadeh, M., Singh, J., Gomaa, I., Elsagan, N.. Kinateder, M., Ma, C., Gaur, A., Bwalya, A., and Sultan, M. 2021. "National guide for wildland-urban-interface fires: guidance on hazard and exposure assessment, property protection, community resilience and emergency planning to minimize the impact of wildland-urban interface fires." *National Research Council of Canada: Ottawa, ON*. https://doi.org/10.4224/40002647.

Buchholz, K. 2021. "Climate change: This is the impact of extreme weather events on the economy." *World Economic Forum:* September 10, 2021. https://www.weforum.org/agenda/2021/09/extreme-weather-events-show-that-climate-change-comes-at-a-cost/.

Bush, E. and Lemmen, D.S. (Eds.). 2019. "Canada's Changing Climate Report." *Government of Canada, Ottawa, Ontario*: 2019. https://changingclimate.ca/CCCR2019/.

Cannon, A.J., Jeong, D.I., Zhang, X., and Zwiers, F.W. 2020. "Climate-Resilient Buildings and Core Public Infrastructure: An Assessment of the Impact of Climate Change on Climatic Design Data in Canada." *Government of Canada, Ottawa, ON:* 2020. https://climate-scenarios.canada.ca/?page=buildings-report-overview.

Center for Climate and Energy Solutions. n.d. "Hurricanes and Climate Change." *Extreme Weather*: Accessed March 24, 2022. https://www.c2es.org/content/hurricanes-and-climate-change/.

City of Boston. 2016. "Climate Ready Boston." *Boston Green Ribbon Commission*: December 2016. https://www.boston.gov/sites/default/files/embed/2/20161207_climate_ready_boston_digital2.pdf.

Commonwealth of Australia. n.d. "About NatHERS." *Australian Department of Climate Change, Energy, the Environment and Water, Nationwide House Energy Rating Scheme:* Accessed February 10, 2022. https://www.nathers.gov.au/.

CSA Group. 2019. "CSA S478: Durability in buildings." *Engineering 360*: April 1, 2019. https://standards.globalspec.com/std/13300506/CSA%20S478.

Davies, R. 2021. "New Zealand – Emergency Declared as Hundreds Evacuate Floods in Marlborough Region." *Floodlist, Australia, New Zealand and Oceania:* July 19, 2021. https://floodlist.com/australia/new-zealand-floods-marlborough-july-2021/.

Eckstein, D., Künzel, V., and Schäfer, L. 2021. "Global Climate Risk Index 2021: Who suffers Most from Extreme Weather Events? Weather-related Loss Events in 2019 and 2000 to 2019." *Germanwatch:* January 25, 2021. https://www.germanwatch.org/en/19777.

European Academies' Science Advisory Council, Leopoldina - Nationale Akademie der Wissenschaften. 2018. "New data confirm increased frequency of extreme weather events: European national science academies urge further action on climate change adaptation." *ScienceDaily:* March 21, 2018. www.sciencedaily.com/releases/2018/03/180321130859.htm.

FAQ 10.2, Figure 1 from Doblas-Reyes, F.J., A.A. Sörensson, M. Almazroui, A. Dosio, W.J. Gutowski, R. Haarsma, R. Hamdi, B. Hewitson, W.-T. Kwon, B.L. Lamptey, D. Maraun, T.S. Stephenson, I. Takayabu, L. Terray, A. Turner, and Z. Zuo, 2021: Linking Global to Regional Climate Change. In Climate Change 2021: *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1363–1512, doi:10.1017/9781009157896.012.

Figure SPM.2 from IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24, doi:10.1017/9781009157940.001.

Forex Capital Markets Australia. 2020. "Financial Impact of 2019-20 Australia Bushfires." May 12, 2020. https://www.fxcm.com/au/insights/financial-impact-of-2019-20-australian-bushfires/.

French Agency for Ecological Transition, Resallience, and French Ministry of Ecological Transition. 2022. "Adaptation of the Building Sector to Climate Change: 10 Principles for Effective Action." *Global Alliance for Buildings and Construction Adaptation Working Group:* October 2021. https://globalabc.org/resources/publications/adaptation-building-sector-climate-change-10-principles-effective-action.

Global Resiliency Dialogue. 2021a. "Delivering Climate Responsive Resilient Building Codes and Standards: Findings from the Global Resiliency Dialogue Survey of Building Code Stakeholders in Canada, Australia, New Zealand and the United States." November 2021. https://www.iccsafe.org/wp-content/uploads/Delivering_Resilient_Building_Codes_and_Standards.pdf.

Global Resiliency Dialogue. 2019. "Findings on Changing Risk and Building Codes." *October 2019 Workshop:* Updated October 27, 2019. https://www.iccsafe.org/wp-content/uploads/Findings_ChangingRisk_BldgCodes.pdf.

Global Resiliency Dialogue. 2021b. "The Use of Climate Data and Assessment of Extreme Weather Event Risks in Building Codes Around the World: Survey Findings from the Global Resiliency Dialogue." January 2021. https://www.iccsafe.org/wp-content/uploads/21-19612_CORP_CANZUS_Survey_Whitepaper_RPT_FINAL_HIRES.pdf.

Government of Canada. 2021. "Canada's top 10 weather stories of 2021." Updated December 21, 2021. https://www.canada.ca/en/environment-climate-change/services/top-ten-weather-stories/2021.html#toc2.

Government of Canada. 2022. "The Program of Applied Research on Climate Action in Canada." *Impact Canada Initiative:* Accessed on March 10, 2022. https://impact.canada.ca/en/behavioural-science/parca.

Hartman, K.J., and Stieve, D.R. 2018. Floodproofing New York: The City's Response to Superstorm Sandy. *33rd RCI International Convention and Trade Show:* March 2018. https://iibec.org/wp-content/uploads/2018-cts-hartman-stieve.pdf.

Henson, B. 2021. "Climate change and tornadoes: Any connection?" *Yale Climate Connections:* July 19, 2021. https://yaleclimateconnections.org/2021/07/climate-change-and-tornadoes-any-connection/.

Insurance Council of New Zealand. 2021. "Private Insurers Canterbury Earthquake Progress to 30 September 2021." *Canterbury Earthquake Progress Statistics:* Quarter 3 Report. https://www.icnz.org.nz/natural-disasters/canterbury-earthquakes.

Intergovernmental Panel on Climate Change. 2022. "Climate Change 2022: Mitigation of Climate Change." *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change:* April 4, 2022. https://www.ipcc.ch/report/ar6/wg3/.

Intergovernmental Panel on Climate Change. 2021. "Regional fact sheet – Urban Areas." *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change:* February 2021. https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Urban_areas.pdf.

International Code Council. 2021. "Global Resiliency Dialogue Second Survey of Building Code Stakeholders – USA: Delivering Climate Responsive Resilient Building Codes and Standards." *Global Resiliency Dialogue:* November 2021. https://www.iccsafe.org/wp-content/uploads/Global_Resiliency_Dialogue_Second_Survey_Report-USA-Oct_2021.pdf.

International Energy Agency. 2012. "100,000 Roofs Solar Power Programme." *IRENA Renewables Policies Database:* July 2, 2012. https://www.iea.org/policies/3476-100-000-roofs-solar-power-programme.

International Finance Corporation. 2021. "Building Resilience Index: User Guide Version 1.0.0." *World Bank Group:* Updated October 27, 2021. https://www.resilienceindex.org/resources.

Jubb, I., Canadell, P., and Dix, M. 2016. "Representative Concentration Pathways (RCPs)." *Australian Government Department of the Environment Bureau of Meteorology, Australian Climate Change Science Program:* November 2016. https://www.cawcr.gov.au/projects/Climatechange/wp-content/uploads/2016/11/ACCSP_RCP.pdf.

Kuligowski, E.D., Phan, L., Levitan, M.L., and Jorgensen, D.P. 2013. "Preliminary Reconnaissance of the May 20, 2013, Newcastle-Moore Tornado in Oklahoma." *National Institute of Standards and Technology, Gaithersburg, MD:* December 3, 2013. https://doi.org/10.6028/NIST.sp.1164.

Multi-Hazard Mitigation Council. 2019. "Natural Hazard Mitigation Saves: 2019 Report." Principal Investigator Porter, K.; Co-Principal Investigators Dash, N., Huyck, C., Santos, J., Scawthorn, C.; Investigators: Eguchi, M., Eguchi, R., Ghosh., S., Isteita, M., Mickey, K., Rashed, T., Reeder, A.; Schneider, P.; and Yuan, J., Directors, MMC. Investigator Intern: Cohen-Porter, A. *National Institute of Building Sciences:* Washington, DC. https://doi.org/10.4224/40002647.

National Oceanic and Atmospheric Administration. 2015. "The 10 Costliest U.S. Tornadoes since 1950." *Storm Prediction Center:* 2015. https://www.spc.noaa.gov/faq/tornado/damage$.htm.

National Research Council Canada Construction Research Centre. 2022. "Delivering Climate Responsive Resilient Building Codes and Standards: A Canadian Perspective." *Global Resiliency Dialogue:* March 2022. https://www.iccsafe.org/wp-content/uploads/Delivering_Climate_Responsive_Resilient_Building_Codes_and_Stds.pdf.

New York City. n.d. "Impact of Hurricane Sandy." *New York City Community Development Block Grant Disaster Recovery:* Accessed March 24, 2022. https://www1.nyc.gov/site/cdbgdr/about/About%20Hurricane%20Sandy.page.

New York City Mayor's Office of Resilience. 2020. "Climate Resiliency Design Guidelines." *Version 4.0:* September 2020. https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v4-0.pdf.

New Zealand Ministry of Business, Innovation & Employment. 2021a. "Ensuring new buildings can withstand liquefication effects." *Building Performance:* July 27, 2021. https://www.building.govt.nz/building-code-compliance/geotechnical-education/ensuring-new-buildings-can-withstand-liquefaction-risks/.

New Zealand Ministry of Business, Innovation & Employment. 2021b. "Global Resiliency Dialogue Second Survey of Building Code Stakeholders – New Zealand: Delivering Climate Responsive Resilient Building Codes and Standards." *Global Resiliency Dialogue:* October 2021. https://www.iccsafe.org/wp-content/uploads/Global-Resiliency-dialogue-second-survey-NZ-report-Oct-2021.pdf.

New York City Department of City Planning. 2012. "Hurricane Sandy: Initial Lessons for Buildings." *NYC Planning:* December 17, 2012. https://home3.nyc.gov/assets/planning/download/pdf/plans-studies/climate-resilience/presentation_sandy.pdf.

Oosterveer, P. 2021. "How the built environment must respond to the IPCC's 2021 climate change report." *World Business Council for Sustainable Development:* August 25, 2021. https://www.wbcsd.org/Overview/News-Insights/Member-spotlight/How-the-built-environment-must-respond-to-the-IPCC-s-2021-climate-change-report.

Overseas Development Institute and World Bank Group. 2015. "Unlocking the 'Triple Dividend' of Resilience: Why Investing in Disaster Risk Management Pays Off." *Overseas Development Institute, London, and World Bank, Washington, DC.* https://olc.worldbank.org/content/unlocking-triple-dividend-resilience-why-investing-disaster-risk-management-pays.

Pacific Climate Impacts Consortium. 2022. "Design Value Explorer." *University of Victoria:* Accessed on February 10, 2022. https://pacificclimate.org/analysis-tools/design-value-explorer.

Porter, K., Scawthorn, C., and Sandink, D. 2021. "An impact analysis for the National Guide for Wildland-Urban Interface Fire." *Institute for Catastrophic Los Reduction:* May 2021. https://www.iclr.org/wp-content/uploads/2021/05/ICLR-SPA-Risk-Impact-Analysis-for-the-National-WUI-Fire-Guide-2021.pdf.

Ritchie, H. and Roser, M. 2014. "Global reported natural disasters by type, 1970 to 2019." *Our World in Data Disasters Emergency Events Database*: Updated November 2021. https://ourworldindata.org/natural-disasters.

Saberi, O. and Beykan, N. 2022. "How to build climate resilience into the construction industry." *World Economic Forum:* March 24, 2022. https://www.weforum.org/agenda/2022/03/heres-how-to-build-climate-resilience-into-the-construction-industry/.

Simmons, K.M. and Kovacs, P. 2018. "Real Estate Market Response to Enhanced Building Codes in Moore, OK." *Science Direct:* 27, March 2018. https://doi.org/10.1016/j.ijdrr.2017.09.040.

Smith, A.B. 2022. "2021 U.S. Billion-Dollar Weather and Climate Disasters in Historical Context." *National Oceanic and Atmospheric Administration:* January 24, 2022. www.climate.gov. https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical.

Sustainability Victoria. 2015. "Energy Efficiency Upgrade Potential of Existing Victorian Houses." *Victoria State*

Government: December 2015. https://assets.sustainability.vic.gov.au/susvic/Report-Energy-Energy-Efficiency-Upgrade-Potential-of-Existing-Victorian-Houses-Sep-2016.pdf.

Swiss Re. 2020. "Annual Report 2020: Financial Report." https://reports.swissre.com/2020/.

Todd, D., Moody, L., Cobby, D., Hart D.E., Hawke K., Purton K., and Murphy A. 2017. "Multi-Hazard Analysis: Gap Analysis Report." *Jacobs. Christchurch*. Prepared for Christchurch City Council by Jacobs, University of Canterbury, Beca, and HR Wallingford. https://ir.canterbury.ac.nz/handle/10092/15312.

United Nations. 2021. "Climate Change Leads to More Extreme Weather, but Early Warnings Save Lives." *United Nations Framework Convention on Climate Change:* September 1, 2021. https://unfccc.int/news/climate-change-leads-to-more-extreme-weather-but-early-warnings-save-lives.

United Nations. 2022. "Number of Wildfires to Rise by 50% by 2100 and Governments Are Not Prepared, Experts Warn." *United Nations Framework Convention on Climate Change:* February 23, 2022. https://unfccc.int/news/number-of-wildfires-to-rise-by-50-by-2100-and-governments-are-not-prepared-experts-warn.

World Bank. 2020. "Urban Development." *Understanding Poverty:* Updated April 20, 2020. https://www.worldbank.org/en/topic/urbandevelopment/overview.

World Meteorological Organization. 2021. "State of Climate in 2021: Extreme Events and Major Impacts." *State of Global Climate 2021 WMO Provisional Report:* October 31, 2021. https://public.wmo.int/en/media/press-release/state-of-climate-2021-extreme-events-and-major-impacts?msclkid=f337c073b95511ecbd7685cc72302396.