ICC INTERNATIONAL CODE COUNCIL®

Global Resiliency Dialogue Second Survey of Building Code Stakeholders – USA

DELIVERING CLIMATE RESPONSIVE RESILIENT BUILDING CODES AND STANDARDS

NOVEMBER 2021

INTERNATIONAL CODE COUNCIL®

TABLE OF CONTENTS

ICC INTERNATIONAL CODE COUNCIL®

EXECUTIVE SUMMARY

Communities are becoming increasingly vulnerable to the detrimental impacts associated with a changing climate. As natural hazards continue to intensify in magnitude and occurrences, it is critical for communities to adapt to their unique and changing risks. The development of building codes that draw on both building science and climate science have been identified as an essential strategy to improve the resilience of buildings and communities to intensifying risks from weather-related natural hazards.

The Global Resiliency Dialogue, a voluntary collaboration of building code developers and researchers from Canada, Australia, New Zealand, and the United States, came together to identify strategies and research needs to effectively address evolving climate risks in codes and standards. In January 2021, the Global Resiliency Dialogue published findings of its first international survey in the report, *The Use of Climate Data and Assessment of Extreme Weather Event Risks in Building Codes around the World*. This report is based on a second international survey to capture feedback on current barriers and potential strategies to incorporate future-focused climate science and risk in building codes and standards, representing the viewpoints of U.S. building sector stakeholders.

This report explores the drivers that have the potential to push beyond the barriers to recognize the benefits of resilient building codes and standards, with special focus on the U.S. entities leading the path forward in addressing the resiliency of buildings to extreme weather events. The report also highlights New York City as a model case study to inform the use of forward-looking climate projections in building codes and standards.

There is little dispute about the value of integrating more resilient measures focused on future-looking scientific data into building codes and of fortifying new and existing buildings for resilience against future hazards. However, the challenge is how to achieve balance between protecting buildings in the future with ensuring their present affordability, especially in consideration of vulnerable populations. The survey explores this, and other challenges including the need for universal acceptance and use of current climate science, gaps in existing climate data, inconsistency in existing climate scenarios and uncertainties in risk assessment.

U.S. stakeholders acknowledged that the greatest climate data need is for more localized models that utilize baselines that climate and building scientists can agree upon because adoption and enforcement of building codes in the U.S. is localized. Additionally, the need for more resilient structures is very localized, even based on anticipated hazard events that utilize forward-looking scientific data. Currently, there is a lack of high-quality data at the local scale, which is necessary to inform local codes.

Survey results also highlighted the need for an authoritative source to guide building owners and designers in translating their risks into concrete adaptation strategies. Building owners and designers recognize the uncertainty and the numerous strategies to address future climate risks that are currently used. Stakeholder responses alluded that building owners and designers are seeking an authoritative source to cut through that confusion and provide clear direction.

Current code language does not incorporate up-to-date climate research and provide actionable requirements. This report explores the existing barriers, both from data and policy perspectives, limiting the application of available climate data to proactively incorporate future-looking risk into building codes to enhance resilience. Participating stakeholders highlighted expanded collaboration across sector experts and increased regulation and incentives for resiliency standards as essential actions to increase service life of critical infrastructure in response to the changing climate.

The survey responses concluded that uncertainties of projecting future risk have empowered a business-as-usual mindset, limiting the application of available climate data to proactively incorporate future-looking risk into building codes. There is a sense that climate scientists and the developers of building codes and standards need to agree upon a path and just do it, with the anticipation that the future-looking science will need to be recalibrated regularly as the codes are updated.

Adoption and enforcement of modern building codes and standards to mitigate the impacts of the changing climate is essential. The survey highlights the many barriers in current climate science that have therefore prevented forward-looking climate data to be incorporated into codes and standards as a mechanism for adaptation to enhance building climate resilience.

ICC INTERNATIONAL CODE COUNCIL®

INTRODUCTION

Communities are becoming increasingly vulnerable to the detrimental impacts associated with a changing climate. As natural hazards continue to intensify in magnitude and occurrences, it is critical for communities to adapt to their unique and changing risks. The development of building codes that draw on both building science and climate science have been identified as an essential strategy to improve the resilience of buildings and communities to intensifying risks from weather-related natural hazards.

The Global Resiliency Dialogue, a voluntary collaboration of building code developers and researchers from Canada, Australia, New Zealand, and the United States, came together to identify strategies and research needs to effectively address evolving climate risks in codes and standards. The Dialogue's aim is to create an international resiliency guideline and enable collaborative research efforts that will aid jurisdictions across the globe to better prepare the building stock to withstand the more extreme weather events, including high wind, flooding, and wildfire, that the evidence and science tells us have been and will continue to increase in frequency and duration.

In February 2021, the Global Resiliency Dialogue published findings of its first international survey in the report, *The Use of Climate Data and Assessment of Extreme Weather Event Risks in Building Codes around the World*. A second international survey was conducted to capture feedback on current barriers and potential strategies to incorporate future-focused climate science and risk in building codes and standards. A summary of the results from across the member countries is captured in *Delivering Climate Responsive Resilient Building Codes and Standards*. This report captures the viewpoints of U.S. stakeholders who participated in the international survey.

EXISTING RESILIENCE INITIATIVES

IMPACTS AND BARRIERS

The enormous benefits of implementing codes that make buildings more resilient to future hazards is virtually undisputed among national and local government officials, climate scientists, researchers, and the design community. The benefits include:

- Protection of people from harm and displacement, especially those in the most vulnerable populations;
- 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;
- Improved resiliency of buildings to elements of climate change;
- Faster/less expensive recovery from disasters (including less displacement and need for social services, fewer repair costs);
- Improved community resilience, enabling improved ability to absorb shocks and disruptions and continue critical services and operations;
- Greater peace of mind for building owners, operators, and users – especially for vulnerable populations that are disproportionally affected by natural hazards – who are currently living with the threat of hazard events becoming catastrophic events;
- Reduced exposure to chemicals of concern;
- Less debris from damaged structures that add to landfills, and a reduced need for virgin building materials that increase carbon output; and
- More efficient use of tax dollars.

Despite these identified benefits, there are many barriers to introducing future focused climate resilience into building codes. These are both diverse and wide-ranging, including:

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

- The continual **evolution** in science understanding creates a constantly moving target related to the expected impact of future weather-related hazards over the life of buildings;
- The **scope** of the challenge is daunting, especially in addressing retrofits to the substantial existing building stock;
- The general public's **lack of awareness** of climate change impacts and general and personal hazard risk;
- Limited **communication** about the problem and costs/benefits of resiliency to various constituencies, including builders, owners, developers of codes and standards, policymakers, and the general public;
- **Incentives** to make changes – insofar as they exist – are outweighed by cost, short-term vision, lack of consumer demand for improved sustainability/resiliency, prioritization of individual rights over community health and safety, and the tendency toward inertia (i.e. avoiding the difficulty that accompanies the major changes needed);
- **Desire** for buildings (homes, in particular) that are lower in initial cost and contain attractive attributes without understanding of or regard for the construction practices employed and the potentially detrimental consequences of having foregone built-in resilience attributes;
- **Resistance** to funding or financing the potential higher upfront costs of increased resiliency;
- **Federal bailouts** that have in some cases provided financial disincentives for resilient building construction and safety; and
- **Political will** is lacking, compounded by the decentralized system in the U.S. with non-uniform building code implementation and enforcement which inhibits a cohesive, unified strategy, and coupled with American individualism and the ease and/or preference to focus on shorter-term rather than long-term issues.

DRIVERS

Even in jurisdictions willing to take on the challenge of improving resiliency of buildings, there is difficulty in balancing the need to provide affordable housing (which also drives zoning expansion) with the need to expand the tax base. Therefore, it is critical to explore the drivers that have the potential to push beyond the barriers to recognize the benefits. The variety of drivers is diverse enough to impact the full spectrum of stakeholders in the building safety ecosystem, including:

- Improved public safety, health, and welfare, which is an essential mandate of government systems;
- High and growing cost of responding to increasingly frequent and severe natural hazards;
- The associated human tragedy experienced in each disaster;
- Sustainable materials management;
- The growing understanding and acknowledgement that it simply does not make sense to continue to "pay for stupid" – supporting ideas and projects that don't make long term sense, because they are cheaper and easier today, represent something that has been done before and as a result is less difficult to understand, and therefore face less resistance;
- Equity issues; and
- Business competitiveness and increased pressure from customers demanding "resilience."

Stakeholders in the U.S. recognize numerous entities that are leading the change and beginning to accept the challenge of addressing the resiliency of buildings to extreme weather. Some of those identified include:

- World Federation of Engineering Organizations (in particular, *The Code of Practice on Principles of Climate Change Adaptation for Engineers*);
- American Association of State Highway and Transportation Officials (AASHTO, which receives funding from the Transportation Research Board);
- International Code Council, which develops model codes used throughout the U.S. and jurisdictions around the world (although the updated codes are only useful if they are adopted, implemented and properly enforced);
- American Society of Civil Engineers, which develops model design standards commonly used throughout the U.S.;
- U.S. Green Building Council (USBGC);
- ASHRAE (in particular, Standard 189.1 and new climate change chapter in Fundamentals Handbook);
- Insurance Institute for Business and Home Safety (IBHS);

- The Global ESG (Environmental, Social and Governance) Benchmark for Real Assets, and the real estate industry in general;
- Federal Alliance for Safe Homes (FLASH);
- The U.S. Environmental Protection Agency (EPA) and energy advocates;
- Design professionals;
- National Institute of Building Sciences (NIBS);
- Reinsurance Association of America; and
- Forward-looking jurisdictions like New York City, that have mandated resilient design for capital projects, leading the way by example to introduce resilient design into the local building code.

NEW YORK CITY: A MODEL FOR MAJOR JURISDICTIONS?

New York City (NYC), like many cities around the world, faces challenges resulting from a rapidly changing climate. These challenges particularly stress the delivery of public services and the buildings and facilities that support those services. Recognizing the need to protect publicly funded projects and the need for ongoing city services, the city undertook an initiative to assure capital projects would be resilient to changes in climate.

The city anticipates an increase in the intensity and severity of flooding, precipitation, and heat events over the 21st century. The City's Climate Resiliency Design Guidelines (NYC 2020) were developed to provide step-by-step instructions to go beyond existing building code and standards, by also looking to specific, forward-looking climate data for use in the design of City facilities.

The city formed a 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. 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 (see Figure 1).

While the Guidelines currently only apply to city-funded projects, lessons learned from their application are likely to inform future building code requirements for all projects.

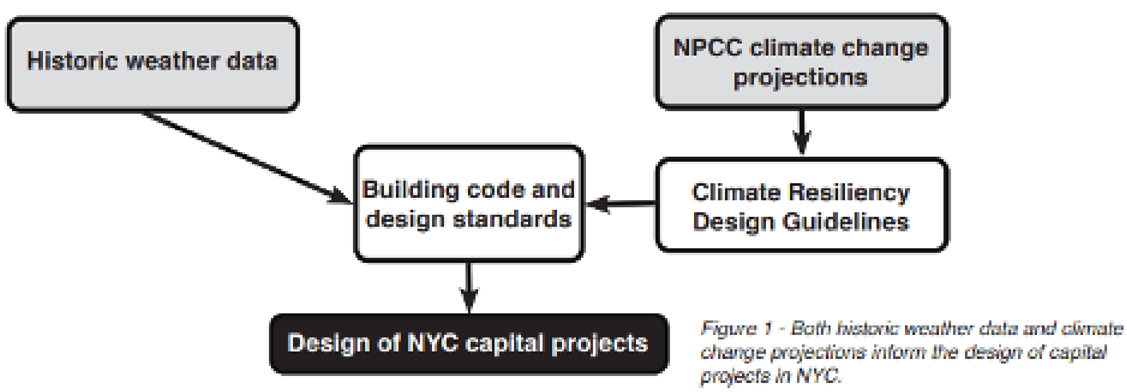

FIGURE 1

INTERNATIONAL CODE COUNCIL®

CURRENT CHALLENGES

DATA AND RESEARCH

Any climate models utilized for code development should be based on peer-reviewed scientific research (government or academic) and should ideally provide a demonstration of various future state possibilities in a way that can be understood by designers, policymakers, and consumers, who need to balance the trade-offs between initial cost and long-term resiliency to projected hazards. To effectively capture the latest understanding and the implications for the built environment, a sustained assessment and implementation process is necessary. While the National Institute of Building Sciences had provided a venue for this dialogue in the past, there are now proposals for the National Institute for Standards and Technology (NIST) and the National Oceanic and Atmospheric Agency (NOAA) to support the incorporation of climate science into codes and standards. To better ensure successful implementation, the private-sector standards development community (including the International Code Council, American Society of Civil Engineers, ASTM international and ASHRAE) and codes and standards users, including architects and engineers, should be heavily engaged in this effort. As a critical function of the implementation, comprehensive monitoring linked to a central database or common portal is needed.

Research data also needs to be translated into forms and formats that are actionable in code and understandable by designers. Outside of fire and seismic communities, there appears (to some U.S. stakeholders) to be a lack of enthusiasm to develop code language that successfully incorporates the latest research.

Specific data needs also include the following:

- Downscaling (see section below);
- More research/data needed for extreme precipitation – rainfall and runoff (i.e., similar to Geoscience Australia's ARR Guidelines, with improved IDF curves that include projections);
- Translation of outputs from global climate model data into inputs for weather files used in building-level energy modelling and other tools to support effective design;
- Models that correlate resiliency measures with the amount of debris generated through the cycle of repairing/ rebuilding following a disaster event;
- Community inventories of buildings (something that has been needed in other resiliency and disaster recovery discussions but never effectively achieved), including special attention to those that store hazardous materials and waste – cataloguing age, structure, materials, locations, resiliency measures – and then applying acceptable risk analysis for various building classifications;
- Insurance data showing cost comparisons of disaster response when resiliency measures are in place vs. not, and the U.S. Federal Emergency Management Agency (FEMA) data regarding repetitive flood losses, re-insurance data showing modelling and projections, and financing/bank data related to post-disaster delinquencies and abandonments; and
- Social science research to anticipate human behaviour during an emergency and inform risk communication.

The perceived need for additional research should not understate the existence of significant research that has already been undertaken in this area by government, universities, institutes, NGOs, and the scientific community, included in the bibliography attached to this paper. The use of this existing research could be better utilized through collaboration with other entities, including:

- National Cooperative Highway Research Program;
- U.S. Department of Defense (DOD) – sea level rise tool – DOD Regional Sea Level Database (limited to DOD facilities);
- First Street Foundation's FloodFactor;
- NIST's National Windstorm Impact Reduction Program;
- National Aeronautics and Space Administration (NASA) – SLR Task Force to make effective use of satellite data to monitor sea level change;

- NOAA – extreme heat programs and Regional Integrated Sciences and Assessment (RISA) teams;
- Centers for Disease Control and Prevention (CDC) – tracking extreme heat across multiple cities;
- Insurance Institute for Business & Home Safety (IBHS);
- U.S. Global Change Research Program (USGCRP) and the National Climate Assessment (NCA); and
- U.S. Climate Resilience Toolkit and Climate Explorer.

The ideal source and format of data for codes is U.S. Government data or global climate models presented in an interactive world map, possibly with a few different scenarios that illustrate potential impacts. Data should be from a trusted source that is peer reviewed, represents the best available science, and is non-partisan. Data should be frank about the uncertainty inherent to climate projections and should have a defensible, repeatable process for updating and archiving.

An example might be drawn from one precipitation prediction tool, the *Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections*. The data in this tool provides users with historical precipitation and temperature values and predictions of the same through 2099 on a daily or monthly basis for a 12km x 12km range for locations within the contiguous U.S. plus portions of southern Canada and northern Mexico. It is developed using downscaling techniques, hydrologic and hydrology projections, monthly bias correction with spatial disaggregation (BCSD) and daily localized constructed analogs (LOCA) climate projections, and based on global climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) and the phase 5 (CMIP5) dataset that informed the IPCC Fifth Assessment. [Although the WCRP's Working Group on Coupled Modelling is now in its Sixth phase and has created CMIP6.]

There are already many organizations – public and private – that are monitoring and conducting modelling that could be used to inform code changes. However, the diversity of work that has been undertaken and reported out to date has sometimes created confusion and an over-abundance of resources. Similarly, much of the content available to date has been contained on websites that are updated or changed, rather than in self-contained, readily citable sources. A new, very hopeful, development involves a collaboration between the U.S. Global Change Research Program (USGCRP) and the White House Office of Science and Technology Policy to create a federal data commons in the cloud and a consolidated climate mapping service that would permit overlay of all federal geospatial datasets with climate data. The partnership also aims to move tools, such as Locating and Selecting Scenarios Online (LASSO) or Climate Explorer, into the cloud as services. Bringing users – including designers and the insurance industry – into the discussion to understand how the data delivery can be optimized for their needs is the next step, which could result in the need for additional investment.

THE DOWNSCALING ISSUE

While one of the aims of the Global Resiliency Dialogue is to identify research gaps that potentially create opportunities for collaborative investment in more useful information to stakeholders in the building safety ecosystem, the consensus from the U.S. contributors to the survey indicates that the greatest need is for more localized models that utilize baselines that climate and building scientists can agree upon. Currently, there is a lack of high-quality data at the local scale, which is necessary to inform local codes.

Generating this local data would require a combination of local expertise and resources and a set of national or international guidelines on methodologies for generating such local data. The localized models should employ nomenclature that is agreed upon and shared by climate scientists and building engineers, for instance related to peak gusts, sea level rise, etc. The models would ideally use climate projections, potentially based on greenhouse gas (GHG) emissions scenarios, that would enable the more endangered areas to prioritize resiliency measures.

RCP FOR FUTURE SCENARIOS?

Currently, there is not much consistency in how risk tolerance is being considered using existing climate scenarios in the U.S. Some architecture and engineering firms have begun incorporating climate risk in their projects, but there is not a universal approach. Fundamental rethinking appears to be required, with building life expectancy, use type, non-stationary weather, and warming scenarios all taken into consideration, together with the new, existential threats that any society has not faced before such as sea level rise or acidification, as well as compound risks from multiple events in short order leading to cascading impacts.

There are strong arguments to be made for a baseline resiliency consideration based on the expected life of the building, particularly the expected life of the building before major repair and/or recapitalization occurs. This should also consider the design building life vs. the realistic building life, since buildings are generally used for longer than their anticipated life at design. Likewise, not every building or structure needs to be designed to the same level of resilience. As with the flood codes' different levels of freeboard for critical and non-critical buildings, one way to address climate uncertainty and manage costs is to recommend ways that highly critical structures (with functions or occupants with a low risk tolerance) plan for worse climate conditions, that would not be generally applicable to all buildings.

One proposed approach to marry these factors for new and existing building projects would be to determine a risk-averse conservative emissions scenario for mission critical sites. From that scenario, one could "backcast" or reverse-engineer from projections on economic loss impact, health impacts, agricultural impacts, water impacts, etc. The reverse engineering should also include an understanding of the adaptive capacity to future scenarios, inclusive of infrastructure dependencies. Performance targets and tipping points on loads that would change the ability to meet those targets could then be identified, allowing code developers and adopting jurisdictions to focus efforts where codes and regulations could provide the most benefit.

Survey respondents were asked what needs to be or is being considered in selecting a future Representative Concentration Pathway (RCP) scenario for design. The RCP scenarios measure the trajectory of greenhouse gas concentration in the atmosphere through the year 2100 that provides relative levels of emissions that will impact global warming from a best-case scenario (RCP 1.9) of below 1.5 degrees Celsius to a worst case scenario (RCP 8.5) under which emissions continue to rise throughout the 21st century. Shared Socioeconomic Pathways (SSP) provide narratives of how societies could look into the future including policy choices and demographics. These scenarios, ranging from SSP1: Sustainability to SSP5: Fossil-Fueled Development, can help predict whether GHG reduction targets are actually achieved, while these models were initially developed largely independently, in recent years, and particularly in the IPCC Sixth Assessment Report, efforts have been made to couple the SSP scenarios with the RCP scenarios to provide a more comprehensive picture of climate change impacts.

The Coupled Model Intercomparison Project phase 6 (CMIP6) scenario that was used to inform the IPCC sixth assessment report (AR6), which references both RCP and SSP scenarios, is important because it will have an impact on the Fifth U.S. National Climate Assessment (NCA5), which is just getting underway.[1] In response to the survey question about RCP scenarios for design, it was noted that, because RCP scenarios are emissions-based, yet many climate policies are indexed to global temperatures, this would necessitate different analytical approaches for the different scenarios. If RCP is used – something about which there was not a strong consensus by those surveyed – the recommendation is to use RCP 8.5/SSP 5 or RCP 7.0/SSP 3 for design but there was some willingness to compromise downwards to RCP 6.0, erring on the side of being conservative, especially for long service life, mission critical assets. There is also the need to continually align RCP and SSP scenarios.

One tool that could be looked at as a partial model is EPA's LASSO tool, which provides access to climate change projections pre-processed for all 10 EPA regions and each of the contiguous U.S. states, with two emissions scenarios, providing summaries both annually and seasonally. However, the EPA tool lacks 'derived' variables (such as days over

---

[1] The U.S. National Climate Assessment is a quadrennial effort conducted by the U.S. Global Change Research Program, a federal program mandated by Congress to coordinate federal research and investments in understanding the forces shaping the global environment, both human and natural, and their impacts on society.

95 degrees F) and spatial needs that would be useful to designers. Another option is the Climate Explorer Tool, hosted by the National Environmental Modelling and Analysis Center, which uses LOCA statistically downscaled climate projections to provide means and ranges (rather than individual General Circulation Models) at the county level. Because climate change will have uniquely local impacts, any solution or tool that is considered will need to have the ability to be calibrated for local conditions.

"[WE ARE] PARTIALLY LIMITED BY CLIMATE SCIENCE BUT THE UNCERTAINTIES IN PROJECTION CAN ALSO BE USED AS AN EXCUSE TO CONTINUE BUSINESS AS USUAL APPROACHES."

– Scott Weaver, Climate Scientist, National Institute of Standards and Technology

RISK ASSESSMENTS

The uncertainties of projecting future risk, coupled with the challenge of addressing something before it is a problem, are combining to contribute to the difficulty of incorporating future-looking risk into building codes. This challenge is exacerbated by differing model assumptions, approximations, parametrizations, data inputs, resolution, and the degree to which climate change will impact the severity and frequency of hazard events. There is also a challenge of tying certain future hazards, such as tornadoes and extreme rainfall, directly to climate change because they tie less directly to temperature.

In order to incentivize the movement towards integrating predictive modelling into building codes, it was suggested to tie resiliency to economic impact and assign a monetary value to future uncertainty. However, such an approach should be mindful of social equity issues where some community members could be left less resilient than others because their buildings or neighborhood may be seen as having less economic value. Engineers and architects can design to protect against extreme hazard, but cost can be a limiting factor, especially as the level of extremity increases. To address this, requirements could be mandated on the basis of the likelihood or probability of an extreme weather occurrence, or on the basis of observed extremes and risk tolerances.

Too often, uncertainties in projections can also be used as an excuse to continue business-as-usual approaches. It is a fact that climate science cannot give us the certainty that we derive from historical data. Some of those limitations can be seen in Figure 2 and Table 1 (both from *Attribution of Extreme Weather Events in the Context of Climate Change*, Figure 4.7 and Table 4.1, Consensus Study Report from the National Academies of Sciences, Engineering and Medicine[2]).

However, this does not mean that the existing science (climate observations and modelling) cannot be used to inform the updating of building codes for future resiliency. The state of engagement (applying the science that we can access) is the challenge more than the availability of climate data. In many cases, we are not even building to address the storms we are seeing today. Something needs to be done now to at least ensure adaptability to hazards that we can already foresee. Since we currently have the ability to predict into the near- to medium-term future (a few years to a couple of decades), we should use the trajectories that we see in some aspects of future climate shifts (extreme temperatures, extreme precipitation, coastal flooding, etc.) to inform updates to building codes. Then, for longer time horizon projections (second half of the 21st century) where predictions are more uncertain, designers can still design for adaptation once risks become clearer or incorporate larger margins of safety by designing to a certain modelling scenario for long-lived constructions.

[2] Both Figure 4.7 and Table 4.1 are used with permission of The National Academies Press, from *Attribution of Extreme Weather Events in the Context of Climate Change* by the Committee on Extreme Weather Events and Climate Change Attribution, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, National Academies of Sciences, Engineering, and Medicine, 1 January 2016; permission conveyed through Copyright Clearance Center, Inc.

In any case, there is a sense that climate scientists and the developers of building codes and standards need to agree upon a path and just do it, with the anticipation that the future-looking science will need to be recalibrated regularly as the codes are updated.

ATTRIBUTION OF EXTREME WEATHER EVENTS IN THE CONTEXT OF CLIMATE CHANGE

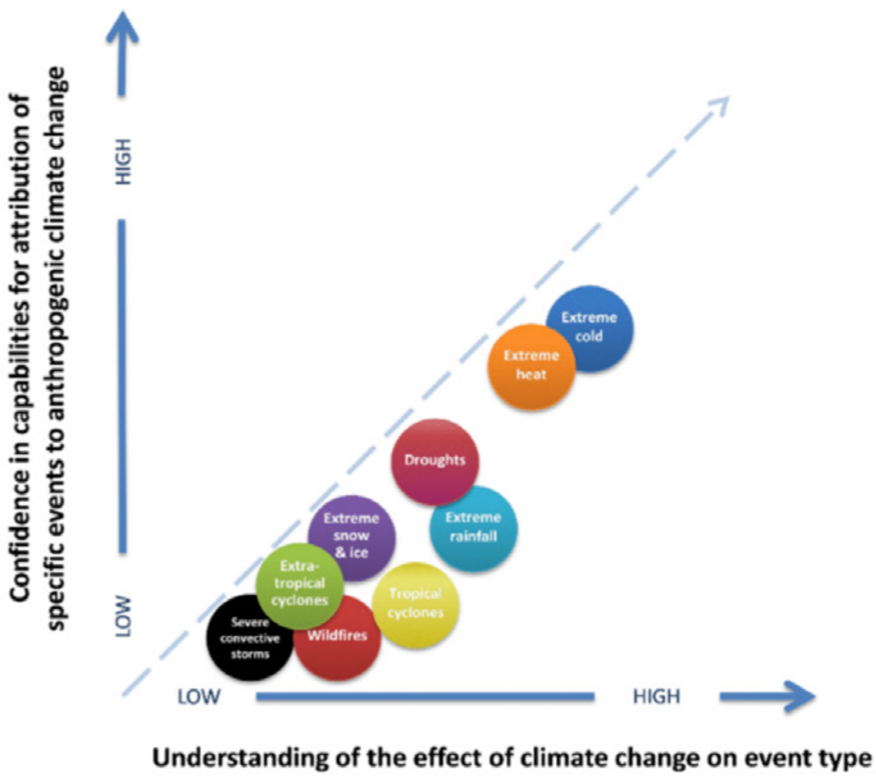

FIGURE 4.7 Schematic depiction of this report's assessment of the state of attribution science for different event types. The horizontal position of each event type reflects an assessment of the level of understanding of the effect of climate change on the event type, which corresponds to the right-most column of Table 4.1. The vertical position of each event type indicates an assessment of scientific confidence in current capabilities for attribution of specific events to anthropogenic climate change for that event type (assuming the attribution is carried out following the recommendations in this report), which draws on all three columns of Table 4.1. A position below the 1:1 line indicates an assessment that there is potential for improvement in attribution capability through technical progress alone (such as improved modeling, or the recovery of additional historical data), which would move the symbol upward. A position above the 1:1 line is not possible because this would indicate confident attribution in the absence of adequate understanding. In all cases, there is the potential to increase event attribution confidence by overcoming remaining challenges that limit the current level of understanding. See Box 4.1 for further details and caveats about this figure.

FIGURE 2

TABLE 4.1 This table, along with Figure 4.7, provides an overall assessment of the state of event attribution science for different event types. In each category of extreme event, the committee has provided an estimate of confidence (high, medium, and low) in the capabilities of climate models to simulate an event class, the quality and length of the observational record from a climate perspective, and an understanding of the physical mechanisms that lead to changes in extremes as a result of climate change. The entries in the table, which are presented in approximate order of overall confidence as displayed in Figure 4.7, are based on the available literature and are the product of committee deliberation and judgment. Additional supporting information for each category can be found in the text of this chapter, summarized in Box 4.1. The assessments of the capabilities of climate models apply to those models with spatial resolutions (100 km or coarser) that are representative of the large majority of models participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5). Individual global and regional models operating at higher resolutions may have better capabilities for some event types, but in these cases, confidence may still be limited due to an inability to assess model-related uncertainty. The assessments of the observational record apply only to those parts of the world for which data are available and are freely exchanged for research. Most long records rely on *in situ* observations, and these are not globally complete for any of the event types listed in this table, although coverage is generally reasonable for the more densely populated parts of North America and its adjacent ocean regions.

● = high **O** = medium ○ = low	Capabilities of Climate Models to Simulate Event Type	Quality/Length of the Observational Record	Understanding of Physical Mechanisms That Lead to Changes in Extremes as a Result of Climate Change
Extreme cold events	●	●	●
Extreme heat events	●	●	●
Droughts	**O**	**O**	**O**
Extreme rainfall	**O**	**O**	**O**
Extreme snow and ice storms	**O**	○	**O**
Tropical cyclones	○	○	**O**
Extratropical cyclones	**O**	○	○
Wildfires	○	**O**	○
Severe convective storms	○	○	○

TABLE 1

ADVANCES NEEDED

Models that can be localized (in some cases, such as for increased rain/flooding and sea level rise, to provide more granular data than the traditional 5km resolution spatially), can incorporate timeframe scenarios for design, and include economic impacts will be the most effective, as they will most easily be understood and utilized by the jurisdictional authorities that are most closely regulating resiliency measures and can help drive building owner support for policy improvements. In particular, visualization tools (similar to energy modelling) and interactive, web-based tools would be most useful. Insurance industry modelling and future-casting information should be made available to support code development efforts.

> "NOT EVERYONE WILL AGREE BUT WE NEED TO GET ON WITH IT. MAKE A DECISION AND EMBED THE REQUIREMENTS IN THE CODE SIMILAR TO HOW WE ADDRESS HISTORICAL AVERAGE CHANGES NOW."
>
> *– Bernie Deneke, Professional Engineer*

Models certainly exist and information is available, but the building engineering community has not been able to effectively articulate how it would use and like to receive such information. Greater dialogue within the building engineering community is needed alongside increased engagement with scientists and data providers. Furthermore, uncertainties about emissions scenarios and long-term climate change make effective modelling difficult, and the design and engineering communities demand greater resolution and certainty, particularly in directional and magnitude shifts, and in ways that tie to economic impact.

Advances are also needed in scale as they relate to different types of hazards. Hurricane modelling has evolved to enable long term future statistics to be extracted (with some uncertainty) from modelling output, but similar scale information is not currently available for severe weather and tornadoes (although progress has been made in understanding how climate change has impacted the environmental factors leading to tornado outbreaks).

As the survey underlying this paper was wrapping up, the U.S. was undergoing a presidential transition. The new Administration has placed a strong priority on addressing climate change including advancing climate science, investment in research and sharing of data. In particular, the U.S. Department of Energy (DOE), NIST and NOAA have more climate-focused activity under the current Administration, but work is still in the development stage. As examples, in early 2021, NIST held a workshop on climate science and building codes, and DOE initiated work on passive survivability standards.

POLICY ISSUES

POLICY IMPLEMENTATION

The central challenge for policymakers is balancing cost, mitigation and resiliency. The model building codes which exist already provide reasonable requirements to ensure resiliency, and can be strengthened based on need and risk level through overlays for stretch requirements. The "above code" provisions certainly increase the up-front costs, tasking policymakers to promote a long-term outlook that considers true life cycle costs. This of course varies based on building type, but also forces an examination of who ***truly*** bears the costs of non-resilient buildings. This can be achieved by a clear analysis of risks and rewards on a project-by-project basis.

Some suggest that investors should require service life accounting and risk modelling for every project, and according to a recent Urban Land Institute report, investors are looking for better data and frameworks to more quantitatively understand and compare risk at a market level to understand whether local investment in resilience is sufficient to mitigate the level of physical risk faced.

POLICY ADVANCEMENT

There are some jurisdictions in the United States that are already making great progress – by necessity – in increasing the rigor of their building codes to ensure greater resilience and providing best practice examples for the rest of the country. New York City has updated its building codes twice since "Superstorm Sandy" to increase freeboard requirements, and more work is underway to introduce larger resilience innovation into the local building codes. The city of Norfolk, Virginia has completely overhauled its zoning codes as part of its future-focused Resilience Strategy. In 2018, the City of Virginia Beach denied an application for a residential development proposal that met technical requirements, but was located in an area threatened by increased flood risk due to expected sea level rise.

> "THIS HAS BEEN THE BIGGEST BALANCING ACT IN MY 30-YEAR CAREER. HOW TO DESIGN AND CONSTRUCT LONG LASTING, SAFE BUILDINGS THAT EVERYONE CAN AFFORD."
>
> – *Cindy Davis, CBO, Deputy Director, Division of Building & Fire Regulations, Virginia Department of Housing and Community Development*

Some have suggested 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. The strengthening of resilience provisions in building codes is most effectively done at the local level, depending upon the level of hazard identified for that locality. However, enhancing model codes or moving to "above code" or "stretch code" solutions can be politically charged especially at the local level. To provide some political cover, the approach taken with earthquake provisions could provide some insight. In this case, earthquake provisions were effectively strengthened following federal-level leadership coupled with a community of design professionals who defined standards and guidelines based on hazard level.

COMPLEMENTARY RESILIENCE TOOLS/ACTIVITIES

A clear communication strategy that embraces risk-based information, based on the same set of facts (i.e. acknowledging that climate change is real), from a unified group of climate and building scientists, presented in clear language would also prove very useful to policymakers. Such a strategy, coupled with supporting policy incentives and disincentives, could likewise be used to educate buyers to demand resilience in their investments, and reject investments that are not adequately resilient.

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 clear cost-benefit analyses utilized by the policymakers and clearly communicated to the general public. This could result in the reconsideration of land use, coastal development and managed retreat policies.

Expanded development and use of building-level resilience benchmarks that can be understood by the public could provide a powerful incentive for builders and developers to exceed code requirements, driven by public demand.[3]

Similarly, some of the existing tools that are commonly used may be due for rethinking, such as Certificates of Occupancy (COO). Typically issued upon completion of construction, this COO process does not allow for the easy imposition of retroactive requirements.

[3] 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.

ADDRESSING LEGACY ISSUES

Policies and incentives that target resiliency in the existing building stock are also 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 are widely cited as strong drivers to encourage wide-scale resiliency improvements. Likewise, a whole-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 suggested policy pathways.

Several examples of successful incentive programs were cited as well, including Enterprise Community Partner's Keep Safe guide targeted to homeowners and multifamily property owners and the general public in Caribbean island communities and South Florida to individually promote and implement resilience strategies, and the U.S. Department of Energy's Weatherization Assistance Program which provides assistance to low-income households to increase the energy efficiency of their homes, thereby reducing energy costs.

SOCIAL EQUITY CONCERNS

Policies driven by the desire for greater social equity are likely to drive implementation of resilience initiatives. In the U.S., land development topics have a complex history, which in the resiliency discussion involve communities that lack rank, access, and privilege being disproportionately affected by hazard events while owners of coastal vacation homes receive compensation for the losses in their second and third homes. These issues and their historical context are addressed at length in the book, "Geography of Risk" by Gilbert Gaul.

Resiliency efforts – and lack of them – have a disproportionately strong impact on these already marginalized communities, including older and poorer members of society who are least able to relocate or fortify their buildings. The City of Norfolk, Virginia recognized and factored this into its Resilience Strategy.

Equity was also a driving factor within the 2018 Federal Alliance for Safe Homes publication, *Learning from the 2017 Disasters to Create a Reliably Resilient U.S.*, which argued that building for resilience is essential to achieve numerous societal goals, including:

- Promoting the embrace of resilience "across the board with no exceptions, no seasons, and no compromise;"
- Combatting the six core biases identified in the *Ostrich Paradox*: myopia, amnesia, optimism, inertia, simplification, and herding;
- Encouraging the use of "modern, model building codes, standards, and floodplain regulations that are adopted on time and effectively enforced are non-negotiable;"
- Repeating the core messages of living resiliently and safely;
- Improving communication to people and communities and leaders before, during, and after disasters, facilitating a two way conversation;
- Making disaster planning more inclusive (old and poor people especially have trouble);
- Not forgetting lessons learned from past disasters so that cycle of Build-Destroy-Rebuild can be broken; and
- Recalling that the costs (economic and societal) of disaster can be decreased by better codes.

COST, MITIGATION AND RESILIENCE

Data that demonstrates the benefit-cost ratio of investments in resiliency, including consideration of the impact of increased waste and debris from damage would be helpful to show the value of investing in resilience. However, in the U.S., the current economics of residential construction do not incentivize resilience. Rather, the focus is on low first cost-of-use, rather than lifecycle costs, and aesthetics, rather than built-in resilient attributes. Regulation that incentivizes resilient construction is needed, and bailouts at the federal level that disincentivize resilient construction need to be more surgically applied.

COMMUNICATION

STAKEHOLDER ENGAGEMENT

In discussions among participants in the Global Resiliency Dialogue, there is wide agreement about the need to improve and target messaging about resiliency to increasingly extreme and more frequent weather events particularly to reach the various audiences within communities. These stakeholders include:

- Natural scientists conducting the research, including earth scientists (geologists, hydrologists, agronomists), environmental scientists, and climate scientists;
- Social scientists, including policy specialists and economists;
- Government, including potential decision-makers at all levels, emergency planning/response agencies, public works and land use planning agencies, and code enforcement entities;
- Code development organizations;
- Industry, including insurance, building materials manufacturers, applied researchers and testing labs, construction professionals (including contractors, laborers, installers, maintainers), real estate developers and agencies, and designers (engineers, architects, landscape architects);
- Community stakeholders, including consumers, residents, community planners/urban planners/smart growth experts, and the deconstruction/reuse/recycling industry; and
- NGOs such as Habitat for Humanity and others.

INFORMATION AND FORMAT

Within each of these stakeholder groups, communication is key. Right now, there is not a common language that is spoken among these varied groups, nor do the groups reference common data. For example, current HVAC and building envelope design relies on weather files with hourly temperature and humidity data based on past weather, whereas future climate data is based on broad timelines that would force designers to consider vulnerability and exposure. Moreover, the method of communication will need to vary by stakeholder group, with some more responsive to graphs, charts, statistics and return on investment calculations, and others requiring infographics and case studies. The challenge cannot be effectively addressed unless it is clearly stated, perhaps using risk-based information (consequences observed and expected) that is designed for consumption by the general public and especially by decision makers. Communication will be most effective when coupled with rationale and incentives provided along with cost-benefit analyses. Ideally, the cost-benefit analyses should include projected vulnerabilities and exposures to be most useful, but this is a difficult endeavour for the same reasons that there are challenges with integrating future risk into building codes.

Providing code officials with the right tools to communicate the importance of resilience is key – code officials are at the front lines of explaining the regulations to owners and designers and need to have the proper understanding of the risks and mitigation strategies, and the tools to communicate this. Shifting the narrative of risk potential measures would be a good start; 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.

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 that fact is fact. Reaching agreement on the fact that warming is occurring is merely the first stage, and a dialogue needs to be created with the understanding that some people believe that the harm caused by “a little” warming is minimal while others predict dire consequences. Case studies and lessons learned are potentially very effective in illustrating possible scenarios and leading to a constructive discussion about potential solutions.

Partnerships among the varied stakeholders to develop proposals on an ad-hoc basis could also serve to advance the discussion. There is wide agreement that success is most likely if adequate investment of both time and money is made in facilitating a cross-disciplinary discussion to ensure broad and holistic identification of problems and solutions. Some suggested approaches include:

- Instituting a stable funding mechanism to support cross-disciplinary research (linking climate science and building science) to compare current codes (including as they are updated) to current climate science and determining the size of the gap;
- Encouraging discussion through (virtual) coffee chats, peer-to-peer networks, an online portal page for discussion/feedback, and other such platforms;
- Engaging the next generation, such as was done in Claire Anderson's program, *Ripple Effect*, about flood awareness; and
- Employing creative means to educate the general public, for example through museum exhibits like the Climate Museum concept in New York City or the National Building Museum's "Designing for Disaster" exhibit, or through creative demonstration, as in the use of lighting to demonstrate sea level rise in Denmark and Finland.

IMPLEMENTATION IN CODES

Regulation, incentives, or perhaps a combination of the two, are needed to change behavior – and will continue to be needed until there is universal public demand for improved resiliency standards. Some of the measures that could be taken to prompt action towards more resilient buildings include:

- Regulation of minimum protective standards (including in coastal land development and water regulations in arid regions);
- Incentives such as priority permitting, tax rebates, federal/state resiliency paybacks, and insurance discounts could be tied to voluntary rating systems (like USGBC's RELi program, IBHS's Fortified program, and Hurricane Strong) to promote stronger building and retrofitting for resiliency;
- Government-funded programs for resiliency (mirroring or even integrated into weatherization programs); and
- Training for architects, building designers, and builders.

As codes and standards are modified to address future hazards, code development organizations may consider thresholds for code changes. Events or metrics that could trigger code changes include:

- Indicators ("tipping points");
- Time schedule;
- Number of disasters over a set period of time;
- Financial cost of damages over a set period of time;
- Availability of commercial insurance;
- Measurement of the impact of climate change on the evolution of compound hazards (i.e., wind + rainfall);
- Level of peril;
- Atmospheric CO_2 ppm with RCP models; and/or
- ISO 31000 risk management standards.

When changes are triggered and proposed by events or metrics such as those listed above, the consideration of code changes should be accompanied by a probability of occurrence and statistical analysis to assess the true necessity of the proposed changes in order to prevent unnecessarily frequent and minor code changes. It is also important to recognize that the thresholds will vary from code to code and hazard to hazard.

There was less consensus about how regularly the climate data referenced in the codes should be updated. Perhaps this could be tied to the availability of new climate data studies, a new scientific consensus around future climate data, the NCA quadrennial, or perhaps based on a pre-established trigger. Alternatively, the climate data in codes could be updated as the codes are updated (3 years for the International Codes used throughout the U.S. and numerous international jurisdictions), or on a different regular basis (4 years, 5-10 years). Equally important – if not more so – is to accelerate the adoption cycles for jurisdictions across the country.

The challenge of future climate uncertainty will need to be addressed within the codes somehow, perhaps 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 and measured against cost. Successful management of uncertainty, such as in seismic code provisions, can provide lessons for achieving resilience to the uncertainty tied to climate change and shifting hazard severity. This type of modelling within the codes will likely require a degree of complexity, and 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).

Any model should also be able to be distilled down to only a few scenarios (i.e., high and low impact) to provide a degree of simplification, and it should also enable evolution as conditions change. We need to recognize that we will always have uncertainty, and this simply necessitates the need to communicate the evolutionary (vs. "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 time horizons. New buildings with a longer life expectancy can be designed with the ability to adapt to changes in future model outputs.

Including a climate resiliency assessment calculation 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 use of modular components could also potentially enable adaptation to changing resiliency needs.

Stakeholders were asked about balancing cultural, heritage and environmental issues in the codes, but not much feedback was received, short of the acknowledgement that decisions involving historic and/or cultural assets are very challenging. The U.S. Department of Defense (DOD) for one has begun to address these items when looking at land use planning.

SERVICE LIFE OF BUILDINGS

When asked about the ideal service life of different building types, there was no consensus – responses ranged from 50 to 100 years and depended on building type, durability of components and site suitability. It was noted that the expected service life of residential construction in the U.S. has decreased in recent years due to the prioritization of exterior appearance and high square footage over long-term quality, durability, or climate readiness of building materials used in the enclosure and the site development/drainage. Among multi-family and commercial buildings, some examples of expected service life include:

- Commercial multi-storied building = 80 years
- General facilities = 50 years
- Drydock facilities = 100 years
- Ideally (but not realistic) = hundreds of years

However, occupancy type and building significance should factor into design considerations – as they already are addressed in the codes and standards used in the U.S., including ASCE7 (facility structural requirements), the Unified Facilities Criteria (for DOD based on mission criticality or storage/support of high-value assets) and U.S. Department of State Overseas Building Operations requirements. More critical-use buildings (i.e. hospitals, emergency shelters, critical infrastructure) and buildings that house more vulnerable occupants need higher levels of resiliency and should be built to higher standards for redundancy and service load/capacity. Figure 3 (from *Cost-Effective Options for the Renovation of an Existing Education Building Toward the Nearly Net-Zero Energy Goal – Life-Cycle Cost Analysis*, by Ming Hu) provides a good example.

However, it is also relevant to consider that most of the serious disaster damage and destruction to structures occurs in single family homes. While each individual loss may not be huge to society, wholistically, the impact to multiple individuals or families and the community (especially for largely residential jurisdictions) may collectively be huge, forcing the reconsideration of what constitutes an "important" structure to that jurisdiction.

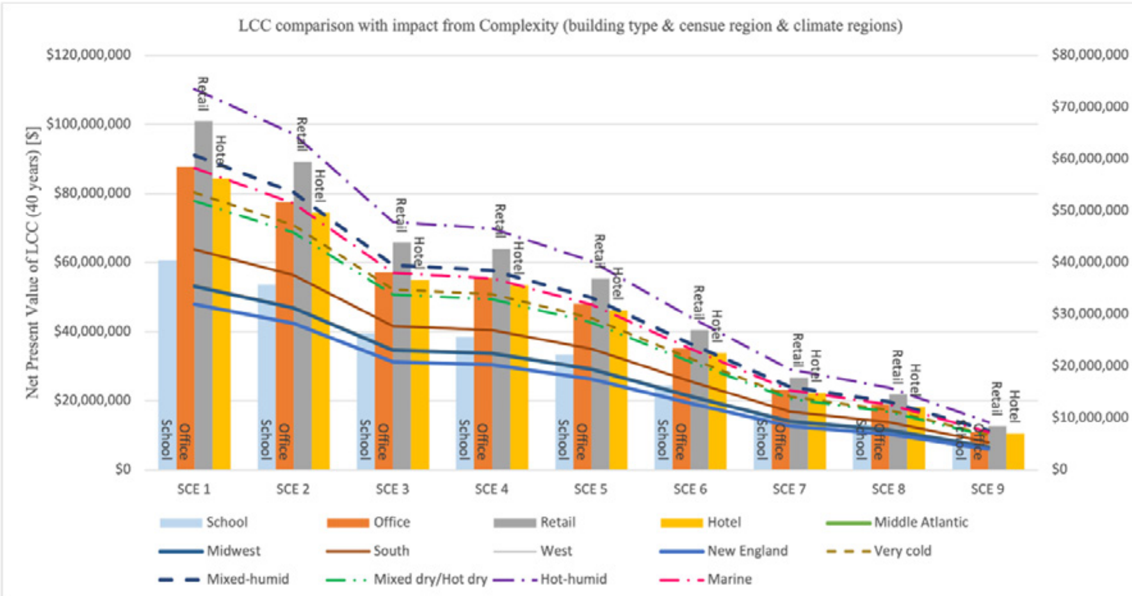

FIGURE 3

Looking more specifically at the expected service life of different systems and building materials, participants suggested wide ranges, including:

- Enclosure – 30 to 75 years
- Subparts (non-enclosure) – 20 to 30 years
- Envelope (windows/roofs/walls) – 40 to 50 years
- HVAC – 15 to 25 years
- Lighting – 15 years
- Controls < 10 years

Despite the ranges, this seems to be in basic alignment with Table 2 (from the New York City Climate Resiliency Design Guidelines), which assist designers of city-funded projects with selecting climate change projections for specific facilities and components.

The wide ranges account for varying quality and durability of materials used and the 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.

Table 1 below provides examples of how to select climate change projections for specific facilities/components.

Table 1 – Facilities and components and associated climate change projections

Climate change projections (time period covered)	**Examples of building, infrastructure, landscape, and components grouped by typical useful life**	
2020s (through to 2039)	*Temporary or rapidly replaced components and finishings*	• Interim and deployable flood protection measures • Asphalt pavement, pavers, and other ROW finishings • Green infrastructure • Street furniture • Temporary building structures • Storage facilities • Developing technology components (e.g., telecommunications equipment, batteries, solar photovoltatics, fuel cells)
2050s (2040-2069)	*Facility improvements, and components on a regular replacement cycle*	• Electrical, HVAC, and mechanical components • Most building retrofits (substantial improvements) • Concrete paving • Infrastructural mechanical components (e.g., compressors, lifts, pumps) • Outdoor recreational facilities • At-site energy equipment (e.g., fuel tanks, conduit, emergency generators) • Stormwater detention systems
2080s (2070-2099)	*Long-lived buildings and infrastructure*	• Most buildings (e.g., public, office, residential) • Piers, wharfs, and bulkheads • Plazas • Retaining walls • Culverts • On-site energy generation/co-generation plants
2100+	*Assets that cannot be relocated*	• Major infrastructure (e.g., tunnels, bridges, wastewater treatment plants) • Monumental buildings • Road reconstruction • Subgrade sewer infrastructure (e.g., sewers, catch basins, outfalls)

TABLE 2

ANNEX I: ACRONYMS

- AASHTO = American Association of State Highway and Transportation Officials
- AIA = American Institute of Architects
- CMIP = Coupled Model Intercomparison Project
- DOE = U.S. Department of Energy
- EPA = U.S. Environmental Protection Agency
- FEMA = Federal Emergency Management Agency
- GHG = Greenhouse Gas
- IDF = Intensity, duration and frequency
- IPCC = Intergovernmental Panel on Climate Change
- JGCRI = Joint Global Change Research Institute (USA, part of Pacific Northwest National Laboratory)
- LASSO = Locating and Selecting Scenarios Online
- NCA = National Climate Assessment
- NIBS = National Institute of Building Sciences
- NIST = National Institute for Standards and Technology
- NOAA = National Oceanic and Atmospheric Agency
- RCP = Representative Concentration Pathway
- SSP = Shared Socioeconomic Pathways
- UHI = Urban Heat Island
- USGCRP = United States Global Change Research Program

INTERNATIONAL CODE COUNCIL®

ANNEX II: RESOURCES

LEADING THE WAY TO RESILIENCE

- *The Code of Practice on Principles of Climate Change Adaptation for Engineers from World Federation of Engineering Organizations*
- *Climate-Resilient Infrastructure: Adaptive Design and Risk Management from American Society of Civil Engineers*

COST, MITIGATION AND RESILIENCE

- *Geography of Risk* by Gilbert M. Gaul
- *Climate Risk and Real Estate: Emerging Practices for Market Assessment*, Urban Land Institute, 2020.

COMMUNICATING THE PROBLEM

- *PIEVC Protocol* from the partnership of: Institute for Catastrophic Loss Reduction (ICLR), the Climate Risk Institute (CRI) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (for public infrastructure projects in Canada)
- *Future Search: Getting the Whole System in the Room for Vision, Commitment and Action* by Marvin Weisbord and Sandra Janoff

RESILIENT DESIGN

- *Cost-Effective Options for the Renovation of an Existing Education Building toward the Nearly Net-Zero Energy Goal – Life Cycle Cost Analysis* by Ming Hu
- *Design Guide for Infrastructure Resilience*, Transportation Research Board
- *Green Strategies for Flood Resilient Cities: The Benevento Case Study*, by Adriana Galderisi and Erica Treccozzi
- *The Cost of Rapid and Haphazard Urbanization: Lessons Learned from the Freetown Landslide Disaster*, by Yifei Cui et al.
- *Earthquake Disaster Waste Management Reviews: Prediction, Treatment, Recycling and Prevention*, by Tomohiro Tabata et al.
- *Climate Resiliency Design Guidelines*. Version 4.0, New York City Mayor's Office of Resiliency. September 2020
- U.S. Environmental Protection Agency Global Change Explorer (GCX) – collection of web tools to plot potential environment change

CLIMATE MODELING/CLIMATE SCIENCE

- *Selecting a Climate Model Subset to Optimise Key Ensemble Properties* by Nadja Herger et al.
- *Applying Climate Change Information to Hydraulic and Coastal Design of Transportation Infrastructure: Final Report*, prepared for the National Cooperative Highway Research Program Transportation Research Board
- *Climate Model Projections from the Scenario Model Intercomparison Project (ScenarioMIP) of CMIP6*, by Claudi Tebaldi et al. (global collaboration)
- *Attribution of Extreme Weather Events in the Context of Climate Change* (Consensus Study Report from the National Academies of Sciences, Engineering and Medicine)
- *Changes in Temperature and Precipitation Extremes in the CMIP5 Ensemble*, by V.V. Kharin et al.