Integrating Climate Change Data into Codes and Standards

Course No: M05-031
Credit: 5 PDH

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This course was adapted from the NIST U.S. Department of Commerce, Publication No. NIST SP 1291, "Workshop on Incorporating Climate Change Data in U.S. Building Codes and Standards", which is in the public domain.

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Acknowledgements

NIST convened a one-day virtual workshop on January 26, 2021 for stakeholders in the building codes and standards community and the climate science community at the request of the U.S. House of Representatives Committee on Appropriations. The workshop addressed climate science data, models, and tools in the context of the planning needs of the building regulatory community.

We thank James Olthoff (NIST) for welcoming the workshop participants and succinctly conveying the workshop goals.

U.S. Representative Matt Cartwright's (PA-08) opening remarks on the need for strengthening America's ability to withstand the challenges posed by climate change set the stage for the workshop deliberations. Representative Cartwright introduced bills – PREPARE Act (2014, H.R.5314) and NIST SUCCESS Act (2017, H.R.1464) – directing NIST to convene efforts to facilitate the availability of consistent, authoritative climate information for standards development organizations (SDOs).

We thank Alice Hill, our keynote speaker, for highlighting the importance of forward-looking climate information in developing building codes for improved building performance; and Zoubir Lounis and Francis Zwiers for providing an overview of Canada's initiative on climate-resilient buildings and core public infrastructure.

Two panel sessions focused on the Building Codes community's data needs in the context of climate change and the availability of pertinent data, models, and tools from the Climate Change research community. We thank the experts from both groups – Dominic Sims, Jennifer Jurado, Don Scott, Birgitte Messerschmidt, Dru Crawley, and Ann Kosmal from building codes, and Roger Pulwarty, Vito Ilacqua, Michael Wehner, Jeff Arnold, and Mike Bosilovich from climate science – for their presentations, and Gordon Gillerman, Terri McAllister, Scott Weaver, and Claudia Nierenberg for moderating the panel discussions.

We thank Andrew Mundy, whose technical expertise enabled the flawless execution of the virtual workshop.

We thank Gwynaeth Broome, Joyce Scott, Emily Walpole, and Dereka Carroll-Smith for helping with reviewing workshop transcripts for clarity and accuracy.

Workshop Organizing Committee

Jason Averill, NIST. Michael Kuperberg, DOE. Therese McAllister, NIST. Andrew Mundy, NIST. Andrew Persily, NIST. Scott Weaver, NIST. James Whetstone, NIST. Jiann Yang, NIST.

Executive Summary

Humans have adapted to natural climate variability and change occurring over thousands of years. However, industrial development at the beginning of the 20th century and its accelerated continuance has generated rapid climate change that now stresses natural and human systems. According to the fifth assessment report from the Intergovernmental Panel on Climate Change [IPCC 2014] and the fourth National Climate Assessment (NCA4) [USGCRP 2017], the human influence on climate is clear and a direct consequence of anthropogenic greenhouse gas emissions that have reached their highest concentrations in history. Human-induced global warming has already caused numerous observed changes in the climate system, including increases in land and ocean temperatures, more frequent and prolonged heat waves over continental regions, increased frequency and intensity of heavy precipitation, and increased risk of droughts in some areas. The extreme events are, no doubt, impacting the U.S. infrastructure and putting lives at risk.

Building codes and standards are fundamental to assuring that buildings protect life during hazardous events and support communities' health, safety, and welfare. One of the foundations for effective adaptation planning is the co-development of plans by stakeholders and scientists for providing urban-scale information about climate risks—both current risks and projected future change to those risks. Codes and standards must incorporate the latest research and data from both building science and climate science to maintain the expected levels of safety and resilience. However, the building codes and climate science communities work largely independently. As a result, the best available climate science may not be fully incorporated into current or future building codes or standards.

NIST and other federal agencies convened a workshop in 2021 to advance the availability of climate information sought by organizations developing standards, model building codes, and voluntary certifications by convening interactions between the building codes and climate science communities.

As a first step, a one-day online Workshop on Incorporating Climate Change Data in U.S. Building Codes and Standards was held January 26, 2021. This workshop brought together the building codes and standards development organizations (SDO) and climate science communities from federal agencies, universities, nonprofits, and the private sector. The workshop focused on two topics:

- An overview of climate data needs for building codes, standards, and state/local officials with a focus on useful data types, scales, and formats.
- An overview of the climate projection data, tools, and reports available from federal climate agencies and organizations.

The workshop goal was to ensure that building codes and standards will have the necessary climate information to fully anticipate the risks these structures will face in the years and decades to come and to ensure that the climate science community understands the needs of the building codes and standards bodies.

Key Findings

The workshop highlighted the need for improved collaboration between building code and climate science researchers and practitioners. In particular, scientific methods to link global climate models to local climate projections, referred to as event attribution, for use by building codes and standards are needed.

At present, forward-looking climate data addresses global climate-related questions and is not tailored to address building code concerns and data needs; climate spatial and temporal resolutions can be much larger than those required for codes and standards. Building codes need climate projections at local scales to inform criteria for future building design and risk assessments.

It should be further noted that development and adoption of guidance into standards and model code can take a decade or more, followed by local adoption of model codes that can take years [Hayhoe et al 2018; Sweet et al 2022]. Thus, there is an urgent need to start addressing climate issues for code adoption now.

The Gaps

Climate Data and Information for Building Codes and Standards

Clear guidance is needed about the type and format of data and information that building code developers and users require from climate scientists. This process could start with translating the information needs of the codes and standards community for use by the climate science community. Specific climate data products for building codes need to be identified, such as projections for wind, snow, and rain intensity and flood elevations that include sea level rise.

Critical issues need to be identified that may affect design practice using building codes when applying climate projections from global models at a local scale (referred to as event attribution). One of the critical issues is developing new or modified approaches to address future hazard events that cannot be based on past events. Another critical issue is to ensure that climate projections in national model codes meet local needs. Consistent, standardized downscaling mechanisms are needed that are pertinent to the building code community, without losing key information from climate models.

Effectiveness of Climate-Informed Building Codes and Standards

Buildings are a major contributor to greenhouse gas emissions [Gurney 2018]. To support new building practices and their impact on climate change, improved measurements of GHG from buildings and infrastructure are needed. The costs and benefits of mechanical and HVAC equipment, building envelopes, and structural systems that reduce carbon emissions also need to be quantified.

The development of a comprehensive methodology for characterizing future building and infrastructure performance and risks is needed to assess the vulnerability of buildings and infrastructure to climate change impacts. Examples include land use policies, hazard maps, risk assessments, insurance policies, insurability of buildings, social equity, and vulnerable populations. Many times, those most affected by disasters or climate change are most at risk and are least financially capable of adapting or recovering. Land-use policies are needed for sea level rise, increased precipitation, drought, and other climate impacted hazard events. Insurance companies could develop strategies and finance mechanisms to support the adoption of building codes and standards that address climate risks.

Leadership and Education

Leadership is needed to manage and advance the interaction between climate and building code communities by one or more agencies and/or organizations, including interactions between those responsible for sources of climate data and models, developing of codes and standards, and end users of climate information and codes.

Public education and awareness of climate impacts on communities is needed for improved understanding and awareness of changing risks to communities and their buildings and infrastructure from future climate impacts.

Next Steps

Given the lead time for developing science and implementing it in guidance, standards, and codes, the time to act is now. There is an urgent need to link forward-looking climate data with codes and standards for resilient buildings, infrastructure, and communities.

Climate change is already straining communities, and their existing buildings and infrastructure. Building codes do not currently account for future climate change effects. Codes and standards need to consider both structural integrity and building and infrastructure performance to achieve community resilience and enable rapid recovery of functionality. To accomplish these goals, interactions between climate scientists and code researchers and developers need to be initiated and facilitated.

For productive, long-term collaborations, the following series of steps are needed due to the years-to-decades it takes to develop and adopt consensus codes and standards:

- Convene a consortium of stakeholders and partners to lead and guide climate and code collaborations. Stakeholders include developers and users of climate information and codes and standards. Partners include national and international experts that can help advance climate science and its implementation. The US should learn from and collaborate with organizations conducting similar activities in other countries, including Canada, the European Union, New Zealand, and Australia.

- Produce a framework with a timeline for short- and long-term efforts to identify climate information needs by codes and standards organizations and what is available from current and emerging models. A summary list of federal and state agencies and organizations that are sources of or contributors to climate science and/or building codes would provide insight into their respective roles.

- Conduct a series of coordinated efforts, such as workshops, seminars, publications, data sets, and guidance documents, by climate and code communities to specify available climate information and gaps, including spatial/temporal scales and associated uncertainties, for codes and standards. The data types and quality may vary between products that support GHG emissions, weather events (e.g., precipitation and wind), wildfires, sea level rise, and other climate-related effects on buildings and infrastructure.

- Refine the framework based on the abovementioned activities and include timelines for developing climate information that can be used by codes and SDOs. For example, climate information may include future hazard projections for floods due to sea level rise or changes in precipitation due to changes in atmospheric and ocean temperature.

1. Introduction

Safety and resilience are common goals for societies adapting to climate change-related risks. According to the Second Assessment Report on Climate Change and Cities [Rosenzweig et al. 2015], disaster risk reduction and climate change adaptation are the cornerstones of making communities and their infrastructure resilient to a changing climate. Human-caused climate change presents significant risks to communities beyond the familiar risks from natural climate variations and seasonal weather patterns. Integrating these activities with a city's development vision requires a new, systems-oriented approach to risk assessments and planning.

The Global Resiliency Dialogue recognizes that the building codes adopted in most countries, based on historical climate and weather data, cannot provide the same safety and performance level as in past years and decades [Zakresky 2020]. Since past hazard events are inadequate in conveying emerging and increasing climate risks, systems-based risk assessments should be based on current conditions and forward-looking climate projections.

Codes and standards are fundamental to assuring that buildings support communities' health, safety, and welfare. One of the foundations for effective adaptation planning is co-developing plans with stakeholders and the scientists who can provide community-scale information about climate risks—both current risks and projections of future changes in hazard events. To advance beyond local efforts to address climate issues, codes and standards require an approved mechanism to incorporate the latest research and data from both building science and climate science to maintain or improve the expected levels of safety and performance.

1.1. Objective

The workshop's main objective was to bring the building codes and climate science communities together to take stock of climate data needs, especially the type, format, and scale of climate projections at pertinent spatiotemporal scales and tools. The goal is to advance how codes and standards will account for climate risks that buildings will face in the years and decades to come.

1.1.1. Background

The NIST workshop was convened at the request of the U.S. House of Representatives' Committee on Appropriations. NIST, in consultation with the U. S. Global Change Research Program (USGCRP) and the Mitigation Framework Leadership Group (MitFLG), convened an ongoing government-wide effort to provide forward-looking climate information to Standard Development Organizations (SDO) and to reduce federal fiscal exposure by enhancing the resilience of infrastructure to the consequence of climate change [GAO 2016]. A steering committee of experts on climate science and codes and standards developed an agenda and identified the workshop speakers to focus on two topics:

- Provide an overview of SDO needs for climate change data.

- Provide an overview of climate projection data, tools, and reports available from federal climate agencies and non-governmental organizations.

The workshop included speakers from federal agencies, communities, universities, nonprofits, and the private sector. It also featured panel discussions to identify gaps in the implementation of climate information in building codes and to identify future actions to address these gaps.

The report presents pertinent background information on building codes and climate data and projections, and the main findings and recommendations from workshop presentations and panel discussions.

1.2. Building Codes

National building codes address public health, safety and welfare and provide minimum requirements for the design, construction, alteration, and repair of buildings. National model building codes are maintained by the International Code Council (ICC), and new editions of the International Codes are published every three years. The ICC's family of International Codes[1] includes the following:

- International Building Code
- International Energy Conservation Code
- International Existing Building Code
- International Fire Code
- International Fuel Gas Code
- International Green Construction Code
- International Mechanical Code
- International Plumbing Code
- International Residential Code
- International Wildland Urban Interface Code
- International Zoning Code

One of the most cost-effective ways to safeguard communities against anticipated damage and losses from natural disasters is to adopt and enforce the latest version of the model building codes. Building codes help communities reduce casualties and building damage as well as indirect costs such as business interruptions and lost income [FEMA 2021].

It is the responsibility of state and local jurisdictions to adopt and enforce building codes. Today, all U.S. states, the District of Columbia, and territories have adopted one or more building codes at a state level [ICC 2021]. However, up to 65% of counties, cities, and towns across the U.S. still have not adopted modern building codes [FEMA 2020]. This disconnect is due to the variations among states in how building codes are adopted and enforced.

[1] www.iccsafe.org

Local building officials are responsible for enforcing building codes within a jurisdiction, which may not be based on the latest or recent national model building codes. Building code enforcement is achieved by reviewing design plans, inspecting construction work, and issuing building and occupancy permits. In areas that have not adopted building codes, it is the designer and general contractor's responsibility to ensure they incorporate building codes in design and construction documents.

A recent study [FEMA 2020], focused on buildings constructed since 2000 (~20% of the 100+ million buildings in the U.S.) and direct losses from earthquakes, flooding, and wind events. The analysis estimated that, from 2000 to 2040, cities and counties with modern building codes would avoid $132 billion in losses from natural disasters, and that avoiding losses is best addressed by expanding the national adoption of modern building codes.

Green construction and energy conservation codes seek to improve residential and commercial building efficiency in energy and water consumption and carbon emissions, and to diminish their negative impact on the environment. However, green codes do not currently address future climate issues.

At present, design criteria for natural hazards are based on historical data and statistical models for reliability and risk assessment, where past hazard events are considered representative of future hazard event frequency and magnitudes or intensity (referred to as stationary conditions). While global climate models are being used to identify greenhouse gas (GHG) effects, such as increasing air and water temperatures, their impact on natural hazard events may require new methods for characterizing future hazards due to the nonstationary effect of climate trends. For example, heating, ventilation, and air conditioning (HVAC) systems use outdoor temperature data for system performance analysis, which are available from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Weather Data Center [ASHRAE 2020a]. ASHRAE Standard 169 provides climate data based on historic data for building design and sizing building energy systems and equipment [ASHRAE 2020b].

However, none of the building codes currently contain methods or guidance that allow designers to include the projected effects of climate change for future conditions or hazard events. The challenge is to develop building codes and standards that incorporate forward-looking climate information, so buildings can withstand the threats imposed by weather and climate extremes in the coming decades and over the life of buildings. While HVAC systems may have a nominal service life of 25 years or so, structural and building envelope systems may have a nominal service life of 50 to 100 years. The development of climate-informed building codes requires strengthened coordination between the SDOs and climate science community.

1.3. Climate Data

Weather and climate are closely related but have distinct characteristics. Weather is the state of the atmosphere (temperature, precipitation, humidity, wind, etc.) and water bodies (sea-level, waves, surface temperature, etc.) at a point in time, while climate refers to the characteristics of weather elements over periods of time through statistical properties (e.g., probability distributions and associated means and standard deviations). The averaging period is typically 30 years, as defined by the World Meteorological Organization (WMO). The 30-year weather data is referred to as the Climate Normal and is updated every ten years [WMO 2017]. The establishment of a climate normal allows comparisons between a specific day, month, season, or another period normal with the climate normal values. Such comparisons characterize anomalous weather and climate conditions, climate variability and change, and help define unusual or changing weather and climate events [Arguez et al. 2012].

Humans have adapted to natural climate variability occurring over thousands of years. However, industrial development at the beginning of the 20th century, and its accelerated continuance, generated greenhouse gases that have resulted in increasing rates of climate changes that are stressing natural, built, and human systems. According to the fifth assessment report from the Intergovernmental Panel on Climate Change [IPCC 2014] and the fourth National Climate Assessment (NCA4) [USGCRP 2017], human influence on climate is a direct consequence of anthropogenic greenhouse gas emissions that have reached their highest concentrations in history. The global climate has changed relative to the pre-industrial period (1850-1900), with multiple lines of evidence indicating that these changes have impacted organisms, ecosystems, and human systems and well-being [Hoegh-Guldberg et al. 2018]. Human-induced global warming has already caused observed changes in climate systems, including increases in both land and ocean temperatures, more frequent and prolonged heat waves over continental regions, increased hazard event frequency and intensity, and heavy precipitation events at the global scale, as well as an increased risk of drought.

The observed frequency, intensity, and duration of some extreme weather events have been changing as the climate system has warmed. Such changes also have been simulated in climate models, and some of the reasons are well understood. For example, global warming is expected to increase the likelihood of extremely hot days and nights, cause more evaporation that may increase atmospheric moisture and the frequency of heavy rainfall and snowfall events. The extent to which climate change influences an individual weather or climate event is more difficult to determine. Nonetheless, this relatively new area of science—often called event attribution—is advancing. The ultimate challenge is to estimate how much climate change has affected an individual event's magnitude or probability of occurrence. Such results remain subject to substantial uncertainty, with greater levels of uncertainty for events that are not directly temperature related (National Academies of Sciences, Engineering, and Medicine 2016).

As noted previously, building codes do not currently address future weather and climate conditions. This is in part due to the issues related to event attribution, moving from global models to local predictions.

Climate models are based on well-documented physical processes and seek to simulate the energy and materials transfer through the climate system, which consists of oceans, atmosphere, land, and the cryosphere. Climate models use mathematical equations to characterize the transfer processes using specified initial values of model variables, influenced by climate forcing changes, and solving these equations using powerful supercomputers [https://www.climate.gov/maps-data/primer/climate-models].

Climate models predict the future climate under various scenarios. The forward-looking data produced by the global climate models are known as climate projections. Climate research institutions generate climate projections for a range of assumed scenarios that capture the relationships between human choices, emissions and concentrations of greenhouse gases (GHG), and temperature changes. Some scenarios represent continued dependence on fossil fuels, while others evaluate actions to reduce emissions. The resulting range reflects the uncertainty inherent in quantifying human activities (including technological change) and their influence on climate [USGCRP 2017].

The World Climate Research Programme (WCRP) Working Group on Coupled Modelling (WGCM) oversees the Coupled Model Intercomparison Project (CMIP). The objective of the CMIP is to better understand past, present and future climate changes arising from natural variability or in response to other changes. The availability of past climate simulations and future climate projections is made possible by the Earth System Grid Federation enterprise system [ESGF 2021]. CMIP climate simulations and projections informing the IPCC assessment reports.

Within the United States, the U.S. Global Change Research Program (USGCRP) coordinated the selection of scenarios and tools from the CMIP5 climate projections for NCA4. The NCA4 report includes a suite of high-resolution scenario products generated from statistical downscaling of climate projections, including the scenarios [USGCRP 2018], the Data Tools and Scenario Products in the appendix of the NCA4 report [Avery et al, 2018], and the Climate Explorer [NOAA 2021].

The WCRP Coordinated Regional Downscaling Experiment (CORDEX, [Bukovsky and Mearns 2020]) provides global coordination of regional climate downscaling efforts for improved regional climate change adaptation and impact assessment. In this effort, regional climate models are used to downscale the CMIP5 climate projections, deploying dynamical rather than statistical methods. The high-resolution climate projections for North America obtained using this strategy are available from the National Center for Atmospheric Research (NCAR) Climate Data Gateway [WCRP 2021].

The Intergovernmental Panel on Climate Change (IPCC) released their sixth assessment report (IPCC 2021), “Climate Change 2021: The Physical Science Basis”. The Working Group I contribution to the Sixth Assessment Report addresses the most up-to-date physical understanding of the climate system and climate change, bringing together the latest advances in climate science, and combining multiple lines of evidence from paleoclimate, observations, process understanding, and global and regional climate simulations.

Phase six of the Coupled Model Intercomparison Project (CMIP6) [Eyring et al. 2016] presents a set of global climate projections for downscaling to improve regional climate change-related risk and adaptation assessment.

2. The Workshop2

2.1. The Need for Interagency Cooperation and to Act Now

2.1.1. Welcome and Opening Remarks

Dr. James Olthoff

NIST Acting Director

Dr. Olthoff welcomed attendees to the workshop and provided an overview of NIST's mission and work, noting NIST's role in developing measurement science to advance building codes and standards.

> "Climate change by any measure is a grand challenge confronting our entire nation. I'm really pleased today to explore one of the more significant underlying dimensions of this challenge, ensuring that our nation's infrastructure is built to last. Not just for the conditions and hazards of today, but mindful of and prepared for the conditions and hazards 50 to 100 years from now."
>
> *Dr. James Olthoff*

NIST leads the National Windstorm Impact Reduction Program, a multi-agency program (with NOAA, FEMA, and NSF) authorized by Congress to achieve major measurable reductions in the losses of life and property from windstorms through a coordinated federal effort. NIST also has a proud history of conducting rigorous technical investigations of the impacts of natural and manmade hazards on our built environment. Under the authority of both NWIRP and the National Construction Safety Team Act of 2002, we are currently investigating the effects of Hurricane Maria on the island of Puerto Rico. We're addressing how critical buildings and designated safe areas within them performed including their dependency on electricity, water, transportation and other infrastructure, how to characterize the wind environment during the hurricane, and how building and infrastructure conditions led to injuries and deaths. We're also investigating how emergency communication systems performed and the public's response to those communications. And lastly, the storm impacts and recovery of selected businesses, hospitals and schools, and the critical social functions they provide. NIST is also studying the devastating 2018 Camp Fire in Paradise, California that destroyed and damaged over 19,000 structures and resulted in 86 civilian casualties and three firefighter injuries.

We are privileged to have Alice Hill, a true thought leader for the Council on Foreign Relations, and a cross section of leadership for building construction in the US. Also, we have a cross section of experts in climate science, including climate data, modeling, and tools, representing numerous US federal agencies as well as our international partners. The panels will be followed by a discussion of the available climate science data and models and tools by representatives of NOAA, NASA, USACE, EPA, and DOE.

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[2] The workshop remarks are a summary of the remarks and may be edited convey the sense of each speaker without being a direct transcript of the remarks.

2.1.2. Congressional Remarks

Congressman Matt Cartwright

Pennsylvania 8th Congressional District

Congressman Cartwright serves as the chair of the House Appropriations Subcommittee on Commerce, Justice, Science, and related agencies, and is a member of the House Natural Resources Committee. He provided a Congressional perspective and motivation for the workshop, and outlined relevant legislation related to climate change and building codes.

Remarks

I want to thank members of NIST, NOAA, NASA, EPA, DOE, GSA, our state and local partners, private sector representatives, and the many standard setting organizations for being here today, to discuss what I truly believe is a critical, but too often overlooked aspect of our climate change preparedness.

Over the last decade, extreme weather costs for the federal government totaled more than $320 billion. And of course, it costs the private sector far more in ways we can measure, and in so many ways we cannot.

President Biden has laid out his bold plan for a clean energy revolution and has stressed the importance of environmental justice. In fact, on his first day in office, one of his actions as President, was signing an executive order to recommit the United States to the Paris Climate Agreement. We're optimistic that the President's agenda, combined with unified democratic control of government, will open the door to the truly transformative climate agenda we need. We've been reactive to climate change for far too long, we have to be proactive and make changes before it's too late.

> "As you all know, climate change is fundamentally going to change our lives over the coming decades. We know business as usual is not going to cut it. Our future is not going to resemble what has come before. One of the best and simplest ways that we can prepare ourselves for this future. Is to ensure that our building standards are using the best available science to account for our future and avoid relying on historic climate patterns."
>
> *Congressman Matt Cartwright*

One of the key ways I use my influence in Congress to fight climate change is through my position on the House Appropriations Committee. I was given the honor of being voted to chair one of the 12 subcommittees of Appropriations, the CJS subcommittee, Commerce, Justice, and Science. Many of the organizations represented here today, including NIST, NOAA, NASA, and NSF, fall under the jurisdiction of this subcommittee and get funded by it. In my capacity as chairman, I will do all I can to ensure you have the resources to continue and expand the important work that you all have been doing. The more I can understand your work, the issues you face, the better advocate I can become to fund your work as we go forward.

Funding is just one step toward addressing the climate change crisis that all of us face in this country. As you all know, extreme weather events are complex, cross-cutting problems that pose risks to many economic and environmental systems, including agriculture, infrastructure, ecosystems and human health, and present a significant financial risk to the federal government as well. In 2019 alone, the US had 14 weather disasters costing $1 billion or more. From 2010 to 2019, extreme weather events resulted in 602 Presidential Major Disaster Declarations, 119 events that each inflicted at least $1 billion in damage, and a total of 5,217 fatalities, and $802 billion in economic losses caused by these $119 billion events. Every dollar spent on hazard mitigation brings a $6 return on investment. The federal government is currently not well organized to plan for and address the fiscal exposure caused by extreme weather events. And it doesn't sufficiently focus on pre-disaster mitigation, or fully budget for recovery activities after extreme weather events happen.

> “We're now facing a reality that is far too common across the country. Our modeling in the 1980s and 1990s simply did not properly take climate change into account. … Now despite tens of millions of dollars invested, my constituents in Wilkes-Barre Pennsylvania are once again dealing with floods and officially living in a floodplain again. … To me, this only underscores the critical importance of climate forecasting and building infrastructure that will stand the test of time. We need to look into the future, understand what is to come, and build our infrastructure today to respond to conditions that may not materialize for decades.”
>
> *Congressman Matt Cartwright*

In 2014, when I was serving as ranking member of the House Committee on oversight and government reforms subcommittee on economic growth, job creation, and regulatory affairs, I requested a Government Accountability Office, GAO, review of the use of climate change information in design standards, building codes, and voluntary certifications. In fact, when putting out the report, GAO concluded in 2016 that standard setting organizations generally had not used forward-looking climate information and developing standards. They noted several reasons why this might be the case, including the inability of standard setting organizations to locate the best climate related data, as well as models. And I know a lot may have changed in the past several years since this report was issued. I think that we can all agree on the importance of using forward-looking climate data in creating standards. And that's why we've all gathered here today.

My district understands firsthand the need to utilize forward-looking climate data because right now we're experiencing the devastating consequences of flooding. The Susquehanna River in Northeastern Pennsylvania is one of the most flood prone waterways in the United States. My constituents and the federal government invested tens of millions of dollars into building and then expanding a flood wall to protect thousands of homes and businesses against the 100-year flood event. We thought we had solved the problem, and for a long time it largely worked. The Army Corps of Engineers estimated the wall has prevented over $7.5 billion in damage from floods. But because of climate change in recent years, we've seen these 100-year flood events happening with regularity now. That means they have to buy flood insurance, their homes are devalued, and they face the constant threat of flooding itself, in their homes.

We want to do everything that we can to enable the success of the vital work that you are all doing. The standards that you all create and implement protect American lives and American livelihoods. Around the world, a lack of accountability in building codes and standards leads to unnecessary health and safety risks. Without adequate codes and standards, we're leaving the most vulnerable populations to fend for themselves.

When we talk about climate change, this problem is multiplied exponentially. Our standards have to keep up with our changing environment. You don't have to look any further on this question than the windstorm related fires, storms and other climate change related natural disasters around the country. To see the destruction caused to infrastructure when building codes and standards fail to meet today's challenges. Standard setting organizations like yours have the ability, not only to hold individuals accountable, but also to ensure a safe future. Solving these challenges is going to require cooperation among members of Congress, the private sector, and the other experts in the world including in the digital room here today. I appreciate your participation in this ongoing dialogue.

As more time passes without action, the price of climate change inaction for building codes and standards increases a lot, doing the most harm to our most vulnerable communities. Now more than ever, a pragmatic and targeted approach to addressing climate change through building codes and standards is vital. Meaningful successes can only be achieved through a broadly supported and practical approach. My guess is that pretty much everybody in this virtual room would agree that we're well overdue for major investment in our infrastructure. Something that's been discussed for years but not seriously.

If we're going to invest trillions in our infrastructure, we need to do it in a forward-looking and sustainable manner. That's why what we're discussing here today is so timely and so critical. You're all indispensable to our ability to build back better and build for the future. You all set the standards to make sure we're using the best science and the best modeling. Your expertise is vital in helping us develop building codes and standards, sustainable building materials, and resilient, sustainable buildings. The work that each of you does has a tremendous impact on the day to day lives of citizens of this country. I know that your work is often thankless, and I want to take the opportunity to tell you how deeply grateful we are for you and your work.

In closing, I'd like to thank you for your time and your willingness to make positive change for the future of our nation, and our planet. Infrastructure and climate are a top priority for the Biden Administration. And they have been for me as well and the effectiveness depends on the work that all of you are doing. Collaborative workshops and sessions like these are going to provide greater clarity across the whole enterprise.

We do have a tendency to stovepipe information. The ability to use this venue to share lessons learned and build meaningful relationships is going to prove crucial as we continue to refine systems, processes and procedures in dealing with the ever-evolving threat of climate change. During today's closing session, there's going to be a summary of identified gaps, needs, and future actions that need to be taken.

We can't afford to waste any more time denying the science of climate change. Nor can we waste any more time with inaction that has to stop. We have to act swiftly and boldly to address these challenges before it's too late. I look forward to working with all of you listening to your concerns and your proposals and standing with you to get you the assistance and the resources that you need to build us all a better future.

Thank you all for listening and thank you for your tremendous work.

2.1.3. Keynote Address

Judge Alice Hill

David M. Rubenstein Senior Fellow for Energy and Environment

Council on Foreign Relations

Prior to her position at the Council on Foreign Relations, Judge Hill was a special assistant to President Obama and Senior Director for resilience policy on the National Security Council where she led the development of national policy to build resilience to catastrophic risks. Recently, she co-authored a book entitled *Building a Resilient Tomorrow*. Judge Hill has worked and thought about climate change and resilience, both inside and outside of government.

Remarks

> *"In all my work on climate change, I've realized that building codes is where it all starts."*
>
> Judge Alice Hill

I got my first introduction to the issue of resilient building codes when I joined the White House as an advisor to Lisa Monaco, who was then the Homeland security advisor. As many of you recall, Superstorm Sandy caught the United States by surprise. It served in my opinion as a wake-up call for many within the federal government to the type of massive destruction that climate change can bring.

That event alone caused over $60 billion in damages. Overtopping Manhattan's 12-ft flood barriers, storm surge led to a cascade of infrastructure failures that started with electric substations and impacted hospitals and energy, wastewater, and transportation infrastructure. Over 8 million people lost power, hospital basement generators were flooded, 6500 patients were evacuated down darkened stairwells, tunnels were flooded, and billions of gallons of wastewater spilled into neighboring waterways.

We know that Sandy was more intense, it was bigger, and its rainfall heavier as a result of climate change. That's become clear in recent years as our attribution science—that's the science that tells us how these events are worsened by what percentage—tells us they are worsened by climate change. And it used to be, when I first joined the White House, I had to be very careful. We can't tell if a particular event was worsened by climate change. But now the attribution scientists can tell us that almost all of these new extremes we're experiencing are worsened by climate change.

President Obama formed the Hurricane Sandy Rebuilding Task Force in recognition that the nation was unprepared for these types of disasters in the future. And that's how I got involved in building codes. When I arrived at the National Security Council, I was told my first assignment was to develop a National Flood Risk Management Standard. The Hurricane Sandy Rebuilding Task Force had directed that the NSC, the security arm of the White House, develop the first standard that would apply whenever federal money was used to build in or near a floodplain. President Obama signed an executive order that created the Federal Risk Flood Management Standard, ten days before Harvey.

Research from Stanford recently concluded that one-third of the damage caused by flooding, our most damaging natural hazard, is already being affected by climate change. But we have other challenges ahead, be they higher winds, hotter temperatures, more extreme precipitation, deeper droughts, or bigger wildfires. The nation will suffer these extremes even if we cut our emissions to zero tomorrow. That's a very important point here. We have baked in future heating across the globe as a result of past emissions. There's a delayed effect that we result in future extremes even if our efforts to cut our emissions are successful.

All of our infrastructure has been built on the assumption that the past resembles the future—that assumption is just no longer true. The past can no longer safely guide the future. When I started working on climate change, most people I encountered assumed that climate change was something for the distant future. Maybe it had something to do with polar bears. But unfortunately, climate impacts have moved firmly into the present, and they are now accelerating, but we're not accounting for them yet.

It's been a long time since I studied math, but here's one problem set I've never forgotten: the lily pads on the pond. Once you take a walk by a pond with a single lily pad at its edge. Suppose that every day you go by the number of lily pads has doubled. On the first day there's one, on the second day there are two lily pads, on the third day there are four, and on the fourth day there are eight and so on. So, here's the math part. If the pond is covered completely by the 48^{th} day, when was it covered halfway? The correct answer is on the 47^{th} day. If you didn't get that right, you're not alone. We're seeing exponential growth in the risks from climate change. And we need to act now.

In fact, in my experience, many are surprised to learn that after 40 days of exponential growth, you would barely notice the lily pads as they'd only cover 1/256th of the pond. And that's why I think it's been like that for climate change. People will just don't see it yet, so they don't quite believe it. Our brains tend to assess risk based on our own past experience. That's called the availability bias. But it turns out that bias in our decision making is hindering our ability to prepare for a future that will have accelerating climate harm. It's easy to ignore the steady exponential growth and the lily pond for a long time until those lily pads smother the pond.

In addition to the devastation of the pandemic, 2020 walloped the planet with worsening climate impacts; 18 of the 19 hottest years since 1800 have been recorded in the past two decades. There was a record-breaking storm season in the Atlantic with so many named storms that we had to turn to the Greek alphabet to name them. And the word gigafire, when more than a million acres of land burned, has come into our vocabulary. California saw twice as much land burned this year than it had in its recorded history. It also saw probably the highest recorded temperature on Earth, with 129 degrees Fahrenheit in the very aptly named Death Valley. According to NOAA, the United States blew through its past record of billion-dollar disasters in 2020 with a total of 22. Those are the disasters that cause more than a billion dollars in losses for a single disaster. According to the reinsurer Munich Re, global losses from natural hazards grew to $210 billion. I still don't think most professionals appreciate what's ahead as they've had no formal education in climate change. Typically, if they're baby boomers, this just wasn't part of the curriculum. It was really treated as a niche issue, something that had to do with the environment. If you're a millennial or a Gen Z your chances of having had any education on this issue of climate change isn't that much better. Based on a 2016 survey of the top 100 universities and colleges according to the US News and Report Rankings, researchers calculated the likelihood of a student taking at least one climate change course, just one, as a part of the core curriculum offered at those schools was less than 20%. As far as I can tell our architecture and engineering schools similarly still do not require students on a routine basis to study climate change, except for a few majors, possibly like environmental engineering. So it's not surprising that climate change, and in particular the vulnerabilities they create, for example the siting of buildings and how they're constructed, just haven't made it to the top of the agenda yet. It's been nine years since Hurricane Sandy swept through and we still don't have model building codes or standards for climate worsened risks, or any system to ensure their adoption and enforcement at the local level.

> "If we don't account for the changing risk, but instead continue to assume that the past is going to resemble the future, we will increase our vulnerability to harm. This means that we have to consider how climate change impacts affect where and how we live. And that's where this group comes in. To prepare for accelerating extremes, communities must consider the future risk of climate change as they make those important decisions about existing and future development."
>
> *Judge Alice Hill*

Even some of our best codes for dangers like wildfire have struggled in the face of climate change. Take California's groundbreaking code from 2008 on wildfire. It required fire-resistant roofs, siding, and other safeguards to keep buildings from igniting. California has used this building code for new construction in wildfire-prone areas since 2008. But even that code proved inadequate in the face of climate worsened wildfires in 2018. One study by McClatchy showed that only 50% of the homes built to the new standard in the path of the 2018 Camp Fire escaped damage. Now admittedly, this is a lot better than the old standards did, when only 18% of the homes went undamaged, but in my opinion 50% is hardly cause for celebration. With temperatures rising, never imagined record breaking events increasingly strain the systems and infrastructure upon which people rely.

To prepare for accelerating extremes, communities must consider the future risk of climate change as they make those important decisions about existing and future development. Better building codes with strong enforcement can help get us there but the United States needs to move quickly to improve its code. That means the code councils working together with experts on climate information to develop the model codes we need, just as the GAO, the Government Accountability Office, government watchdog recommended that we do in 2016. This has to be a priority going forward for the nation that simply can't wait.

As we work to respond to these growing risks, we also need to change our focus. The focus of building codes must move away from simply saving lives. Of course, it's important to save lives but now we also have to look at building's performance. Building codes should work to preserve the building's ability to function post disaster, rather than simply ensuring the safety of its occupants. In other words, codes should cover a building's performance during and after a calamity, ensuring that buildings and infrastructure can function as intended in the wake of a disaster, and assist communities and households in recovering much more rapidly while saving lives, livelihoods, time, money.

Performance building codes can promote greater resilience because they get communities back on their feet faster. Kids are back in school, businesses are reopened, people can get back to their lives. And that means that they are safer, happier, all of us are better off. Performance codes focus on the ends rather than the means to determine what a structure is required to do, rather than prescribing what size those studs need to be in the building. It looks at the building's performance.

Japanese engineers have pioneered performance codes for earthquakes to address their very great seismic risk. I vividly remember a story that a Japanese expert told me about his experience with performance codes. He lived in Sendai Japan, 15 miles away from the center of the Tohoku earthquake in 2011. The night before the earthquake, his family had gathered and they celebrated some occasion. They lifted champagne flutes, drank champagne, and the next morning they went to town on a trip.

The earthquake occurred, my friend returned to his home, and he discovered not only that his apartment in a highrise was standing, but also those champagne flutes on the kitchen counter were still standing there. That's remarkable. The apartment was unscathed. Other earthquake prone countries, including Peru, Turkey, Chile, China, Mexico and Italy have followed Japan's performance-based approach to building codes, and to certain degrees, New Zealand.

If the United States adopted performance codes, we would have to account for the future impacts of climate change worsening events. That would mean that in lower Manhattan and cities across the nation, we would have the type of structures that would prevent the kind of flooding that we saw in Sandy. Our model codes as we go forward need to account for the altered conditions brought by climate change over the course of a building's life. They also need to address building performance after disaster strikes. We need those buildings up and running so that we can continue on with our business.

If communities build homes only to fail, they are not solving their affordable housing problems. They are contributing greater emissions to our already serious climate change troubles. They will struggle to recover economically when people are forced to relocate to other areas in search of housing and functioning businesses.

Performance-based building practices will help communities get back on their feet, bounce back, just as they did in Sendai for my friend after that devastating occurrence. Of course, the added resilience must be weighed against the added cost of construction. But we need to look at the life of the building and adjust our cost benefit calculus accordingly.

Beyond just performance codes for particular structures, we also need to develop approaches that address the interdependency of hazards, and the effect of climate change on increasing vulnerability. More Sandy's and bigger Sandy's are in our future. We need to understand how to halt the cascading failure of infrastructure. Because all of our systems, and our decisions about infrastructure, the financial system, or health system, or national security, have been based on the assumption of a stable climate. The climate that no longer exists.

We see time and time again, businesses, governments, and communities caught unprepared just as we saw with Sandy and this is the most important thing I can leave you with: the human brain has a difficult time, we're optimists, we don't think these events will hurt us. That's what our polling shows most Americans believe that climate change is real, but they don't believe it's going to affect them. We also see our availability bias. We think we can judge based on the past experience to what the future will bring. Just watch how many media reports include something after a big storm, like I've lived here for 50 years, and I've never seen anything like this before. Well, that really isn't newsworthy because new extremes are ahead, yesterday's extreme will be exceeded by next year's extreme or the extreme in a decade. All of us need to internalize the fact that today's one-in-100-year record could be a one-in-25-year event in the not-too-distant future, and that one-in-1000-year flood event could be the one-in-500-year flood soon.

That's why Houston saw so many, one-in-500-year flood events in a row. If we could internalize this, we would definitely make different choices than we are right now. The news about climate change today isn't that it's happening, it's that it's accelerating. The Lily pads are doubling, this is an all-hands on-deck problem. We need everyone finding ways to cut harmful greenhouse emissions to avoid the very worst of heating. We must cut emissions and that has to be part of our building codes as well. But also, we need to prepare for the further impacts we will suffer in the foreseeable future. We need to account for future climate risks as we choose now, where, and how we build. Performance based resilient building codes are going to help us get there.

2.2. The Canadian Example: Zoubir Lounis and Francis Zwiers

Dr. Zoubir Lounis

Principal Research Officer, National Research Council of Canada

Construction Research Center

Dr. Lounis is internationally recognized as a leading authority on deteriorating infrastructure. He made notable contributions or breakthroughs on infrastructure deterioration, modeling of risk-based design and asset management, and the design of high-performance infrastructure. Zoubir was awarded the prestigious Ernest E Howard award in 2018 and the Ty Lin award in 1999 from the American Society of Engineers.

Remarks

I am going to provide an overview of Canada's initiative on climate resilience building and core public infrastructure. This large initiative was led by NRCC, the National Research Council of Canada. We acknowledge the funding from Infrastructure Canada over five years. It started in 2016 and is finishing in 2021 with more than 150 partners covering different disciplines: engineering, building and infrastructure engineering, science, climate science, building owners, and different stakeholders.

Canada's buildings and the infrastructure are designed and evaluated using codes and standards that are based on the historic climate data and loads that don't consider the impacts of climate change. It is the same situation as in the US. We know that in Canada, the climate is warming, on average, about double the magnitude of global warming. This is a serious problem in the north. Precipitation is projected to increase for most of Canada, with a shift towards less snowfall and more rainfall, with increased risk for flooding.

Another assumption that is in our codes and standards is that climate data and the associated climatic laws that we use for design are assumed as stationary within the design life of building and infrastructure. We know that's not true. We have also observed regional differences in the uncertainty or coefficient of variation of climatic data for wind or snow. This led to a non-uniform level of reliability across Canada using the uniform hazard design approach that we use right now. For example, we specify in our building code and bridge code a 50-year return nominal climatic load for wind and then we multiply it by a loss factor or safety factor which are 1.4 for wind and 1.5 for snow. As a result, we find quite a large variation in the probability of failure across Canada and the way that the target reliability is specified for buildings and bridges. So we need to adopt a uniform risk approach to ensure a more uniform reliability across the country.

The impact to change that Judge Alice Hill and Congressman Cartwright mentioned was that climate change will lead to increased climatic load. Climate change is a multibillion-dollar problem for Canada, similar to the US. Decreased capacity will increase the probability of failure of infrastructure as there will be an increase in extreme events. In terms of intensity and frequency for extreme heat, wind, and flood, as seen especially in Alberta floods and wildfire, there will be an increased rate of deterioration due to warming which will lead to reduced capacity and safety. All of this will lead to increased disruption, loss of service and function of critical infrastructure that are essential for the sustainability of Canadian communities. This will in turn lead to higher maintenance, rehabilitation adaptation or replacement cost.

We need to develop codes based on future climate data taking time to climate change. To do this, we partnered with the National Research Council (NRC), Environment and Climate Change Canada (ECCC), and the Pacific Climate Impacts Consortium (PCIC) to develop future climatic data for the design of buildings and infrastructure. NRC provided the expertise in model codes, building science and engineering, while ECCC and PCIC have the expertise in historical climate data, climate modeling, and projection of future climatic data. This was an ambitious undertaking to determine future climate data for the many climate parameters that we use in the National Building Code of Canada. So this partnership led to the development of this future climatic law and the results were published in 2020.

Now, my colleague Francis will discuss climate modeling and the development of future climate data.

> "Our objective was to develop decision support tools, including code guides and models for design, evaluation of building and core public infrastructure that take into account the impact of climate change and extreme weather events. It included buildings, bridges, roads, transit, potable water, stormwater and wastewater systems."
>
> "This initiative is in support of the Pan-Canadian framework on clean growth and climate change and in support of the Green Infrastructure Objective of the Canadian government."
>
> *Dr. Zoubir Lounis*

Dr. Francis Zweier

Director of the Pacific Climate Impacts Consortium

University of Victoria

Dr. Zweier's former roles include Chief of the Canadian Centre for Climate Modelling and Analysis, and Director of the Climate Research Division both at Environment and Climate Change Canada. As a research scientist, his expertise is in the application of statistical methods to the analysis of observed and simulated climate data. Dr. Francis Zweier is a Fellow of the Royal Society of Canada, the American Geophysical Union and the American Meteorological Society and a recipient of the Patterson Medal and President's Prize. He has also served on the intergovernmental panel on climate change and leadership roles for the fourth and fifth assessment reports.

Remarks

The scope of the project was undertaken by three teams working to update climatic design values that are listed in the Canadian building code and the bridge code. These are based on historical data to project design value changes for future climate and to develop a mapping tool for presentation of data that's appropriate to extremes for a country with generally sparse data coverage.

> "The change in reliability over time may not be monotonic, some loads will increase, others will decrease. Knowing how the overall reliability varies with time for a given piece of infrastructure will be important."
>
> *Dr. Francis Zweier*

A little bit about the updated climatic design values that are based on historical data: this is the first comprehensive update of all tabulated building code elements for a very long period of time. Quality control was performed following methods described by Durre et al (2012). Durre works at the National Climatic Data Center in Ashville, NC. We used some very innovative data processing approaches to cope with continued decline in the coverage of the Environmental Climate Change Canada observing network and to utilize, in the case of snow, relatively plentiful snow depth data and snow load updates. We made some minor adjustments to stream value analysis methodology that was being used after an extensive evaluation of several alternatives. We performed the objective interpolation of station-based design values to the tabulated locations. In the past, the process would have used expert review and judgment to make some further adjustments to the objectively determined values. Because of the large, wholesale comprehensive effort undertaken this time, that wasn't possible.

We noticed that the effect of global warming is particularly evident in temperature related climatic loads, such as the 1% and 2.5% January hourly temperatures. Here is one very quick example of a product that was produced-spatially interpolated 50-year snow loads.

The future design values, led by Alex Cannon at Environment and Climate Change Canada, classified design value elements into three broad tiers depending upon the assessed confidence in the science, with higher confidence in thermal aspects of climate change and warming related aspects and lower confidence in dynamic aspects such as wind pressures. Projections were determined as a function of global warming level relative to recent climate in half degree centigrade elements increments. The idea here is to try to separate uncertainty due to what future emission scenarios might be and the choice of climate model from other sources of uncertainty as much as possible.

An analyst or practitioner using this information would first make a decision about the expected service life of the building. If the service life is 30 or 50 years, for example, then you don't worry very much about the choice of emission scenario at all. If it's a long service life of 75 or 100 years, then you do worry about which emissions pathway we might be on. In that case, you would choose the emissions pathway, then determine the level of warming that might be appropriate for the end of that service life or that piece of infrastructure.

Projections are given as change factors for application to historical design values, sometimes additive, sometimes multiplicative, depending on the nature of the design value. The timing of warming is determined from the ensemble of climate models that participated in the CMIP5 experiment. The IPCC fifth assessment, CMIP6, is now available and we'll be able to update the timing of warming very quickly. We assessed confidence in each design value element and there's a publication that goes into a lot of detail that describes how those assessments were made and what the change factors are.

So here again, considering snow load, is an example of projected change factors at 2ºC additional warming relative to present is based on a model. And you would multiply the current snow loads by a factor greater than one, for locations that are north of 60 degrees North. Everywhere else you would multiply by change factors that are less than one, indicating reducing the loads in the future.

Only a few words about the mapping tool that we developed. We spatially interpolate design values estimated from station data. We use a kriging approach. And to guide the placement of contours in areas where there is relatively little data, which are many in Canada, we use simulated output from a regional climate model as a covariate to describe, guide that interpolation. We're developing an Online Design Value Explorer tool that we hope to have available in beta test version by the end of March for users to begin to experiment with.

And then finally, a few challenges. First, was the sheer scope and ambition of the project, it's a very large undertaking. I mentioned that expert review and adjustment of objectively interpolated tabulated design values hasn't yet taken place and might not be feasible. So, something for the community to discuss is to what extent should expert opinion come into play in the periodic adjustment of design values.

There is climate model dependence - it's very hard to avoid. We've tried to reduce that to the extent possible by separating the impacts of the choice of the mission scenario, and the sensitivity of a climate model from other sources of uncertainty. It's still difficult to say anything useful about some kinds of loads when pressure might be one. The information that we have about the mechanisms to produce intensified winds and climate models is still uncertain. The information that we have from the available suite of global climate models is somewhat equivocal.

A concern is reliability targets in a warming climate. This is something that the engineering community needs to think about very carefully. There are questions about what the design reliability target should be. Whether you should design for average reliability over the expected service life, or this worth, or a specification design specification that addresses minimum reliability over that service life. These are different objectives and have different costs associated with them.

And finally, the move from uniform hazard to uniform risk design procedures that is taking place in the United States requires estimates of extreme loads that correspond to very long period return levels. In the case of wind pressures in the United States for example, the ASCE 7 standard indicates requirements for wind speeds corresponding to periods between 700 years and 3000 years depending on building importance.

2.3. Building Codes View

2.3.1. International Code Council

Mr. Dominic Sims

Chief Executive Officer

During Mr. Sim's 18-year tenure at the ICC, he has also served as their Chief Operating Officer and Senior Vice President. He has been involved in building safety since 1983. Dominic is an expert on the application of building safety technology codes, standards development, and community resilience. He has served and chaired numerous national committees and task forces on a wide range of topics related to building safety.

ICC Actions for Addressing Climate Change in Codes

Remarks

The Code Council works to address challenges that impact the safety of buildings and communities. Our vision is "Creating safe, affordable, and sustainable buildings and communities."

The principal activity is the development of codes and standards for buildings. These standards are applied at all levels of government and in the private sector. Every State in the U.S. and approximately 55 countries use some form of guidance provided by the Code Council. The model code development process incorporates the latest building science technologies and market-ready practices to address changing risk profiles. We do this through continual updates of our Codes and Standards in collaboration with dozens of standards developers.

> Codes and standards universally have traditionally looked to the past to define the level of risk and the appropriate design response. However, the hazard landscape is changing and events are becoming more frequent and intense."
>
> *Dominic Sims*

Hazards like extreme heat days are expected in areas that haven't experienced such events in the past. In keeping with our mission, the Code Council recognizes the need for codes and standards to adapt to address the increasing risk and identify the best path forward.

There is not yet a well-established dialogue between building scientists and climate scientists to understand what information is needed and can be reasonably provided. The Code Council has undertaken a series of deliberate initiatives to address increasing risk.

- In 2014, the Code Council was an initial signatory to the Industry Statement on Resilience led by AIA and NIBS (which now has over 50 signatories).
- The Code Council initiated a dialogue with Standards developers and research organizations from Canada, Australia, and New Zealand who share similar concerns. The recent SES article by Judy Zakreski (2020) outlines this.

- It established the "Global Resiliency Dialogue" and Findings on Changing Risk and Building Codes, both endorsed by international code bodies plus Scotland and private sector organizations including AIA, ULI ASTM.
- The Alliance for National & Community Resilience (ANCR), founded by the Code Council and U.S. Resiliency Council, is developing a set of Community Resilience Benchmarks to support communities in assessing and enhancing their resilience. Each of the benchmarks developed to date (buildings, housing, water) includes provisions focused on identifying and planning for future risks. (Note: The Community Resilience Benchmarks can be used in conjunction with the NIST Community Resilience Planning Guide).

Other projects that we are involved with include working with NIST and FEMA on the definition of functional recovery. We can no longer only focus on the life safety elements of the built environment. We have to begin to look at how buildings respond to more aggressive hazard events. And lastly, we're working on the scope to completely re-develop the international performance code. Now is a perfect time for us to collaborate and expand the application and use of the performance code to address the changing risks presented by climate change.

2.3.2. Broward County

Dr. Jennifer Jurado

Broward County Chief Resilience Officer

Deputy Director of the Environmental Protection and Growth Management Department

Dr. Jurado oversees countywide climate resilience initiatives, water resource policy and planning, environmental monitoring, shoreline protection and marine resources programs. She has been a key figure in the advancement of multi-jurisdictional initiatives with a focus on sustainable water resource management and sea level rise adaptation planning. It played a lead role in the organization and advancement of the Southeast Florida Regional Climate Change Compact, a four-county collaboration focused on regional climate mitigation and adaptation strategies and co-leads the Compact Water Resources and Economic Resilience work groups.

Local Resilience and Climate Change Impacts and Actions

Remarks

The area of Southeast Florida includes the counties of Palm Beach, Broward, Miami-Dade and Monroe. Broward County, where I am located, is immediately north of Miami-Dade County. Collectively our region shares many common characteristics. We're all pretty well developed in the way of coastal communities. We're very flat and low lying, prone to storm surge, and dependent on active flood management systems, which are calibrated to historic sea levels and are drained principally by gravity.

On shared climate mitigation and adaptation strategies, we've had a number of regionally developed documents and guidance. The most significant has been the unified sea level rise projection that was updated in 2019 and adopted by all four regional counties in early 2020. It's the current basis for all coordinated sea level rise adaptation planning in our region. It's utilized by our academic partners and consultants who are required to design in accordance with future conditions. We just updated the planning horizon from 2060 to 2070, as we have been working together for more than a decade.

At present, we largely align our efforts with the NOAA intermediate high sea level projection, which means we're planning for a total of 40 inches of additional sea level rise relative to 2010. Planning for sea level rise does have many implications for our region including issues of land use, planning, and infrastructure siting and design. We're challenged with questions of service, what level of flood protection will we provide in the future? Finished floor elevations is a serious and immediate issue and we're reconsidering development strategies for managing water.

This has been a stepwise process with the evolution of our science and tools. One of the earliest tools we developed was a priority planning map that delineated areas at risk with an additional 2 feet of sea level rise. The map is now being updated for a 3-foot sea level rise scenario in proposed amendments to land use and the county's capital budget process. Any projects falling within that area are subject to a heightened level of review for resilience criteria.

> "Broward County has a strong concentration of urban population. We are fully developed which means that we don't have areas to retreat to and we are already dealing with very acute compounded flood risk. There are high impacts associated with rising seas, and rising groundwater tables given the porous geology and more intense rainfall."
>
> "Recognizing these shared characteristics, about 11 years ago we formed the Southeast Florida Regional Climate Change Compact and we've been working together since that time."
>
> *Jennifer Jurado*

There are some specific regulatory steps we've taken to effectively integrate and coordinate infrastructure planning. A wet season groundwater table map informs design standards for drainage and surface water management systems. As an example, a newly developed county site with a dry retention area was perpetually wet. The groundwater table had changed over several decades, and neither these changes or sea level rise were updated in the standards to inform drainage criteria. We worked with USGS to perform county-wide modeling of a 2-foot change in sea level with a one-to-one change in the groundwater table. A map with a 9% change in the wet season rainfall and 2-foot rise in groundwater table was adopted in July of 2017. It's now the foundation for all development in the county.

The next project involved a collaboration with the US Army Corps of Engineers to address seasonal high tides and overtopping of sea walls. There was a hodgepodge or absence of standards across our coastal cities. The 2-foot increase in sea level was coupled with high frequency storm surge and high tides. A recommendation was made for a 5-foot North American Vertical Datum (NAVD) standard for all sea walls and tidal flood barriers, and other infrastructure. This standard was advanced in March 2019 and was adopted by the County. It requires that our coastal cities adopt this regulation within two years. It also requires that this standard be disclosed as part of real estate transactions for all properties that are tidally influenced.

Another area of work has been an effort to update the 100-year flood map for finished floor elevations. Our county uses a variety of tools for establishing finished floor elevations, including our own community flood map, which includes future changes in land use. This approach has provided some protection in the past for the county, as oftentimes for the last several decades, our 100-year flood map was quite a bit higher than the FEMA flood map. All of the county had a finished floor requirement whether or not the site was in a FEMA flood zone.

As FEMA flood maps were updated, County flood requirements are in some instances now below the FEMA requirement. That has major implications for insurance rates, as FEMA NFIP generally doubles with each foot below the FEMA flood elevation, and we lose discounts for buildings above flood elevation. So the 2014 flood map was updated. We contracted with Geosyntec and brought in a number of technical partners to aid in the modeling analyses. The future conditions for a 100-year flood elevation for a 2-foot sea level rise and high tides were evaluated. Downscaling methods were used to evaluate a change factor for the 100-year rainfall event. A 13% change factor was applied uniformly in that analysis. There was debate about some of the conditions incorporated in the modelling, but the approach of being conservative in terms of assuming extreme high tides, increased rainfall, and supersaturation were reinforced. As the draft map was being finalized, about 35 inches of rain fell over the course of six weeks. This was four times the historic rainfall, with flooding across the county. Each of the flood depths and elevations was converted to more than 368 flood zone areas within the county.

The advantage of employing a new standard to ensure a higher level of flood protection continues to be reinforced by a regional study in partnership with the business community. It quantified the return on investment from investing in resilience standards and infrastructure. The analysis showed that improvements, such as elevating buildings and wetproofing, provided a four to one return on investment. It included preservation of tax base, property values, tourist tax dollars, and economic opportunity associated with key corridors. An average two to one return on investment was found for larger scale systems, with resiliency improvements that might include sea walls, beaches, dunes, and stormwater systems, underscoring the importance of those investments in terms of protecting against losses, reductions in insurance, and holistic economic returns.

These efforts are being applied in a county resilience plan that will set the stage for the organized improvements of infrastructure over the next several decades. While there are certainly many grave and diverse climate related challenges, flood risk is the most immediate. We have substantially benefited through our regional coordination, as well as from the immense support provided by federal agencies and the science and the monitoring that informs the modeling. This provides a robust foundation for our policy recommendations and gives our elected officials the ability to act with confidence. And finally, the business case substantially reinforces the prudence of our actions and the importance of undertaking system wide, community-wide investments in combination with this building specific improvements.

2.3.3. American Society of Civil Engineers

Mr. Don Scott

Senior Principal, PCS Structural Solutions

Chair, ASCE Codes and Standards Activity Division, Executive Committee

Mr. Scott is a Fellow of the Structural Engineering Institute and ASCE and is a thought leader helping to shape national standards for wind loads on buildings. He serves as a chairman for the ASCE 7 Wind Load Subcommittee, and is President for the Board of the Applied Technology Council. He led development of the 2019 Pre-standard for Performance Based Wind Design for ASCE and the Charles Pankow Foundation. Don is at the forefront of structural design techniques and building code changes and provides extraordinary expertise to his clients and colleagues.

Addressing Climate Change in ASCE Standards

Remarks

ASCE is the American Society of Civil Engineers and represents the civil engineering profession across 177 different countries. ASCE is the nation's oldest engineering society and it stands at the forefront of the civil engineering profession that plans, designs, constructs, and operates to support society and the built environment. The society advances civil engineering specialties through nine Institutes.

SEI, the Structural Engineering Institute, has more than 34,000 members in 100 countries. It was established in 1996 and produces many of the standards for loads within the built environment. SEI produces 26 different standards that involve volunteer efforts by more than 700 members. And about half of those 700 members produce ASCE 7.

The future is performance-based design for most of our facilities, and ASCE and SEI are producing performance-based design standards. In the United States, performance based seismic design has been practiced for a couple of decades.

The goal of ASCE 7 is to provide economical and constructible structures that are safe and reliable, that protect our society, and hopefully are a little bit more resilient than what they've been in the past. ASCE 7 defines the minimum design loads and criteria used to design buildings and other structures in the United States. It considers loads for gravity (dead and live loads) and natural hazards (seismic, wind, snow, ice, flood, rain, fire, and tsunami). The 2022 edition of the standard will include tornadoes.

"At present, environmental loads for wind, snow, ice loads, and flood hazards are based on historical data and models. Wind models have been developed for hurricane events, non-hurricane events, and thunderstorm events to account for different wind patterns and recurrence intervals"

Don Scott

A few remarks about code adoption and why it takes so long. First, ASCE 7 is produced every six years. The ANSI criteria for a balanced committee and procedural rules are followed, including a review by public comment. Then the ASCE 7 document is submitted for adoption by the International Building Code. ASCE 7-10 was adopted into the 2012 and 2015 International Building Codes. When ASCE 7-16 was completed, it was adopted into the 2018 and 2021 International Building Codes. As the International Building Code is a model code, it then needs to be adopted by each state and local building officials. Once they are locally adopted and enforced, then the codes can protect public health, safety and welfare of our societies.

So, where does climate change fit within the ASCE process? A new snow load map was completed for ASCE 7-22 to improve reliability and risk across the country. Ice load data from the 1980s and 1990s is being updated. Flood loads are based on the FEMA flood maps. Tornado loads have been based on historical damage data, not actual measurement of the wind speeds in a tornado. A new standard is being developed by SEI to measure tornado wind speeds using Doppler radar and the newest available technologies.

Some provisions for future conditions are being proposed for ASCE 7. This includes procedures or methods to consider climate change factors for environmental loads. Also, the design service life needs to be considered. Most buildings in the past have been designed for a 50-year design service life. Designers are being asked to look at 100-year events and also which one of the climate change predictions should be used: the high, low, or the average? One of the biggest impediments is costs associated with increasing loads. Developers typically own their building for three to five years and don't want to increase the initial cost of construction. Also, our existing building stock dominates the number of buildings that are affected by climate change. Current codes do not require upgrades and so we need to consider different requirements for future climate impacts.

Last, SEI is planning a workshop next spring, with the assistance of Dr. Scott Weaver of NIST, to bring together climate scientists and standards developers prior to the beginning of the next cycle of ASCE 7.

2.3.4. National Fire Protection Association

Ms. Birgitte Messerschmidt

Director of Applied Research, National Fire Protection Association

Ms. Messerschmidt is responsible for NFPA's Research Strategy including global research outreach and represents NFPA in the International Fire Safety Standards Coalition. She manages research on fire problems and other safety issues (e.g. electrical deaths and injuries, CO incidents) using statistical data, detailed incident information, and reviews of relevant literature/research. She has a M. Sc. In Civil Engineering from the Technical University of Denmark and has spent her entire career working on fire safety issues with a focus on fire safety in the built environment. Ms. Messerschmidt has been involved in testing and research as well as standardization and advocacy. She has published and presented numerous papers on fire safety issues.

The Direct Impact of Climate Change on Wildfire and Urban Areas

Remarks

NFPA is a global nonprofit organization established in 1896, devoted to eliminating death, injury, property and economic loss due to fire and electrical and related hazards. Our mission is to help save lives and reduce loss with information, knowledge, and passion.

Today, I'm going to focus on the direct impact of climate change on fire, including the indirect impact that climate change can have on fire safety in buildings. We've all heard a lot about wildfire and how that problem is increasing. At this point, there are almost 45 million homes and existing buildings located in the Wildland Urban Interface (WUI). And over two years in just one state, wildfires destroyed 32,000 homes and cost at least 25 billion in damages. Those same wildfires killed nearly 100 people. So, the past decade has shown 163% increase in structure loss. We are doing a study every year at NFPA on natural fires in the United States. What we have seen over the past years or decades is how wildfires enter into the Wildland Urban Interface, how they are dominating the list of the large-loss fires in the United States.

One approach is suppression. We focus on when the wildfires happen and how to put it out right away. While successful with a lot of smaller fires, the big events can get out of hand. Billions of dollars are spent in suppression, without it actually having the intended effect. There is a disproportionate societal investment between suppression and prevention. According to the U.S. Forest Service, the cost of wildfire suppression in 2017 was $2.4 billion, and that's only part of the total cost because there are other agencies involved whose costs are not included in that toll.

So, a change of perception is needed to realize we cannot control all fires and that not all fires are bad or need to be controlled. If we keep trying to put out all the fires, a bigger problem is being created. Instead, the focus should be on what can be controlled in the environment, and that is the fuel. It's important to realize that wildfires are fueled by much more than trees. Due to climate change, increased rainfall has increased growth and prescribed burns have not been allowed in some areas to clear out some of the brush.

An important area to think about is the Wildland Urban Interface where wildland areas meet urban areas. There is fuel from the trees and the landscaping around buildings. That is something that can be controlled. Last, but not least, are the buildings themselves. When a wildfire enters wooded areas, it becomes a conflagration and buildings also fuel the fire with a combination of natural and synthetic fuels.

What is it that we need to do? How do structures respond to the fire? The landscape around structures, how can we make sure that that's resilient to the fire when it comes in? The community, the type of people living in these areas, how quickly can they get out? How do they respond to fire? These are all important factors, but more information is needed to predict the hazard and quantify the risk.

Accurate risk mapping for wildfire is needed, including land use. Where can we build? Or what is the risk and what should be required in these places? Ignition resistant buildings would reduce the risk of wildfires taking out entire developments. That requires an update of current codes and standards and their use and enforcement.

> "When rebuilding communities after a wildfire, the money spent often does not make them more fire resilient. On the contrary, there are examples of rebuilding after wildfires where codes are relaxed to save construction cost. This is the opposite of what we want to do."
>
> "We need fire resilience through risk management. There is a need to understand fire hazards, and how they are affected by vegetation and topography, as well as the weather and wind. Consequences to the built environment is where we have more control."
>
> *Birgitte Messerschmidt*

There are some important points related to code and standards related to fire risk in the environment. The classic tradition addresses fire in a building with test methods that are between 30 and 80 years old. Work related to WUI needs to be part of codes and standards updates. I want to praise NIST for the work they are doing in this area. Next, fuel management and increased resources for vegetative fuel management on public lands is needed to reduce the size and intensity of wildfires that can threaten communities. Fire departments need to be trained for this aspect. And last, but not least, public education is needed to improve understanding about wildfire construction, maintenance, land use, and evacuation.

A bit on the indirect impact of climate change and fire safety: it is happening as we address climate change. Construction product manufacturers and others are working to mitigate the risks related to climate change, such as reducing CO2 emissions, etc. Energy efficient buildings that are more sustainable may reuse products or new materials and systems, such as insulator facade systems and cross laminated timber. Buildings have controlled air flow, air tightness, and photovoltaic panels on the roofs connected to energy storage systems. All of these can have a huge impact on the fire performance of buildings. When changes are made to mitigate some problems, other problems might result. For instance, the building fire that happened in London in 2017 occurred after that building was energy renovated. Five years later, a fire killed 72 people because it had been renovated with products that were combustible and allowed the fire to spread on the outside of the building. Unfortunately, the renovations introduced a risk in another area.

2.3.5. American Society of Heating, Refrigerating and Air-Conditioning Engineers

Dr. Dru Crawley

Director of Building Performance Research, Bentley Systems

ASHRAE Fellow

Dr. Crawley's expertise is on building performance, building information modeling, net-zero energy, building resilience, sustainability and smart cities with more than 40 years of experience in energy efficiency, renewable energy and sustainability. He has worked in engineering software development, government research and standards development organizations, as well as building design and energy consulting companies. He is also Chair of an ASHRAE Standards Committee.

ASHRAE Resilience and Climatic Data Activities

Remarks

ASHRAE is 125 years old with 55,000 members in over 130 countries worldwide. There are almost 200 chapters throughout the world that are doing research including work to support future standards. Our vision is a healthy, sustainable built environment for all. And a lot of things that are happening within ASHRAE recently are focusing on resilience.

As far as the climatic data activities, we have three key standards:

- ASHRAE Technical Committee 4.2, Climatic Information. This committee updates a chapter in the ASHRAE Fundamentals Handbook. It's a quadrennial update of information for design conditions for buildings, HVAC systems, the envelope, and building standards.
- ASHRAE Technical Committee 2.5, Global Climate Change. This committee primarily focuses on the impact of climate change and ozone depletion from the environment and

also impacts by industry on the environment. This year a new chapter on climate change was published that will go

- ASHRAE Standard 169-2013, Climatic Data for Building Design. The standard has climatic data information for building designs standards.

We produce tables and statistics that HVAC engineers use to design equipment for buildings. It also affects the design attributes related to building energy standards and codes throughout the US. Examples include heating, cooling extremes and temperature degree days. One of the new things added this year is to determine statistical trends. Where there are few stations, simulations of heating or cooling design conditions may also be used.

I authored a paper this past spring that looked at design conditions. The percentiles used are based on the approximate number of area hours within a year. We do not design for the full 100% of all the data extremes. There are design safety factors as well. As an example, based on Washington Dulles Airport data from 44 years ago in 1997, we've seen a small increase in temperature. However, data from 2013, 2017, and 2021 shows that the temperature has come down slightly. So, there are trends in both directions. Generally, over that 44-year period, we are seeing about a half a degree change, but it varies by location.

Also, the new Fundamentals Handbook chapter on climate change includes the climate zone shift. There are areas within North America that have gotten hotter within that framework. The temperature change expected by the middle of the century is also being considered. Data on temperatures is going up more significantly in the Northern US as well as Canada. Much of the data published within the standards are from Commercial Building Energy Standard 90.1, the Residential Standard 90.2, the Data Center Standard 90.4, and the Green Building Standard 189.1. It's also used in indoor environmental quality standards which deal with air flow and pollutants, Standard 62.1 for commercial buildings and Standard 62.2 for residential buildings. These are also used in the national energy codes. With regards to climate zones, there is data for modeling climate zones now throughout the world; when we started, climate zones were primarily focused on North America.

> "Chapter 14 of the ASHRAE Fundamentals Handbook produces design conditions based on data from station-based data. This is primarily from NOAA's National Centers for Environmental information. There is fantastic coverage in North America and Europe, and coverage for Africa and South America is much less in many cases. Every year, the density of data from NOAA improves."
>
> "ASHRAE is also updating its data. A recent update will add 1,000 new stations worldwide."
>
> *Dru Crawley*

We've seen a progression of the climate zones moving north, generally on a four-year cycle, with a few counties right at the edge that may change but not always. Climate zones are not static. A project between NASA Langley and ASHRAE produced graphics showing different climate zones moving over the period of record.

ASHRAE Climatic Data is regularly updated with climatic statistics, but they do not project into the future. The methodologies used for sizing equipment are based on a relatively short term, in the range of 10 to 25 years. The safety factors for equipment design rarely result in situations where full loads will occur over its lifetime. However, many building envelopes have a much longer life, and need future weather information, which is being studied.

A number of workshops and papers on climate change have been sponsored that look at building energy performance. Indications point to a change in where energy is used in buildings, including changes from heating predominantly with fossil fuels. Heating requirements, based on projections, are going to be down significantly and there will be a moderate increase in cooling requirements in the temperate zones of northern latitudes and through our southern latitudes. In areas such as the northern US and Canada, cooling requirements may occur where they've never experienced before.

2.3.6. U.S. General Services Administration

Ms. Ann Kosmal

Architect, Office of Federal High Performance Buildings

Ms. Kosmal safeguards assets from the observed and expected changes in climate for prudent investment, risk management, and augments life safety, public safety, health, and security. She prompts design innovation and bolsters our Nation's global competitiveness in the emerging sector of climate security which cannot be offshored or outsourced. She is a co-author of the United States' Fourth National Climate Assessment's Built Environment chapter. She is a Fellow of the American Institute of Architects, a Certified Passive House Consultant, and a Certified Permaculture Designer.

Safeguarding Assets

Remarks

Safeguarding assets is the topic. I'm going to be approaching this topic through more of a practitioner's position. The bottom-line up front: I'm going to be discussing several entangled topics that then inform practice in architecture and engineering and particularly the use of codes, and how my agency and professional practice can use that to manage risk over time.

I want to particularly recognize all the science agencies that contribute to the USGCRP. I want to recognize the work of two agencies, the US Army Corps of Engineers and the Federal Highway Administration, for their work developing data and information into useful tools and methods that are defensible and repeatable.

Most have heard a good bit about the National Climate Assessment which has risk-based framing. The Fourth National Climate Assessment, Volume Two, Chapter 11, focuses on the built environment. Key message number two reflects the state of science and the gaps that are needed in this arena.

ASCE is a leader in issuing the Manual of Practice on Climate-Resilient Infrastructure with Dr. Ayub as the editor. The American Institute of Architects has an online training series on resilience and adaptation and a certificate series. ASHRAE has an upcoming chapter on climate change in their Fundamentals Handbook. The World Federation of Engineering Organizations has a Model Code of Practice: Principles of Climate change Adaptation for Engineers, which the Canadians helped develop.

This references a direct quote from a paper by Lindene Patton, Esq, of the Earth and Water Law Group: "the duties to adapt physical infrastructure and disaster management plans". This refers to people who have disaster management responsibilities and duties combined with detection and attribution science. See Chapter 3 of the Climate Science Special Report by USGCRP [2017}, which is Volume I of the Fourth National Climate Science Assessment. The combination of those duties and the emergence of climate science for an event could be shown to be 'foreseeable' for a practitioner.

So how does this translate to the arena of practice, particularly at my agency and for architecture and engineering practice, such as the way we work with design teams in developing designs for updating existing facilities or new construction. We ask the same simple question in several different ways:

- Is this place important?
- Why do people gather here to do what?
- Is this an historic or a cultural asset?
- How long will this facility be owned or operated?
- If the answer is 30 years, then what are the observed extremes?
- What is the projected change in the climatic factors over the intended service life of that asset?

> "If a practitioner that is licensed to protect the health, safety and welfare of the public, knowingly did not test the sensitivity of the design to future climate effects, or use it to inform decisions, whether there's a code or whether someone's convinced by the evidence or not, they have 'skin in the game' because there may be damage or someone may be hurt or harmed."
>
> *Ann Kosmal*

Whether the focus is on resilience or adaptation (which are not the same thing but are interconnected, particularly in the arena of vulnerability), design practice seeks answers for: to what, for how long, and for what purpose? In the built environment, the responses to changing conditions are, in a simplistic way, actions to protect, accommodate, or retreat.

The key question for licensed practitioners and their designs, when and how are you doing those things? That relates to the design and its ability to adapt, and to be able to cope with changing loads and stressors. There's a great emphasis put in determining flexibility and the ability for the asset and the design to be able to adapt to changing conditions. Now, what is it that we're actually looking at? We look at the things that cost the most, that last the longest, and are the most disruptive to the occupants and their mission, should they be damaged, impaired, or fail, and basically have a high sensitivity to interruption, relocation, or replication.

This is a simplistic form of decision scaling for climate science, and credit here to Dr. Casey Brown, and many others who study and publish about this topic. This includes defining our problem set, and obtaining the relevant information to answer a scaled-down set of questions about coping and stressors. If we're missing information, where are we going to find credible information to help us to determine whether that information will inform the decision maker? The three climate protection levels for buildings and facilities, thermal, construction, and water, are credited to Bill Gething, an architect at the University of West England, Bristol. Thermal factors focus on the building enclosure, construction factors focus on the durability of enclosure detailing, both above and below grade, and the water factors focus on drainage and the flooding, and the ability to conserve water at a particular site.

From the National Climate Assessment is a statement of what we are really seeking: forward-looking design based on future climate projections to inform investment in reliable infrastructure for changing conditions. Sometimes this is a leadership decision by the owner/operator saying 'this is what our risk tolerance is, this is what our risk appetite is'. The real key here is innovation in materials, systems, and how people approach design. This is all in an effort to operationalize ways to manage these risks over time as this is a risk management function. This requires that folks who work in this arena, architects and engineers, have the capacity, confidence, and capability to approach this topic.

2.4. Climate Science View

2.4.1. National Oceanographic and Atmospheric Administration

Dr. Roger Pulwarty

Senior Scientist-NOAA Physical Sciences Laboratory, Boulder, Colorado

Dr. Pulwarty is the Senior Scientist in the NOAA Physical Sciences Laboratory at the NOAA Office of Oceans and Atmospheric Research in Boulder, Colorado. His research focuses on weather, water, climate and risk management. Dr. Pulwarty has helped design and lead several widely recognized applied programs, including the United Nations World Meteorological Organization climate services information system, the US National Integrated Drought Information System, and the NOAA regional integrated sciences and assessments program. He has been convening lead author on the Intergovernmental Panel on Climate Change, The National Climate Assessment and on the UN Office for disaster risk reduction, global assessments, among others.

Climate Data Provided by NOAA

Remarks

Trends in extreme weather and climate are increasing with trends in population and other factors. NOAA monitors, models, predicts, and makes projections understanding the causes and impacts of weather extremes across multiple trends. NOAA provides practitioners historical rainfall data for rainy days, construction planning, thermal characteristics or buildings, wind use to help properly orient buildings and construct efficient building design. Data from NOAA has also been used in the National Windstorm Impact Reduction Program (NWIRP) to determine long term trends in windstorm frequency, intensity and location, and developing tools to improve hazard assessments, and the storm damage and storm hazard assessments conducted at the National Centers for Environmental Information (NCEI).

One of the goals for NOAA as it pertains to climate planning, is to enhance and simplify access to climate science data and projections through the Climate Resilience Toolkit. This toolkit provides easy and robust access to climate projections for designers, including case studies with calculated and derived variables and adaptation options for planning. The NCEI also provides GIS maps for climate, including tornado and wind climatologies for planning and design. In addition, the Regional Climate Center Program, which is a faction of the NCEI, developed a network of six centers with partners and a system of tools for applied climate information such as vegetation impacts affecting wildfires.

Other national products include those from the Climate Prediction Center, and local climate analysis tools provided by individual weather service offices. All these tools can be used not only to analyze the changes in physical risk, but also the changing risk in the built environment. For instance, heavy urban rainfall increases risk exposure, can lead to closed roads and other cascading consequences, as seen in Hurricane Harvey in Houston, or critical system failures that caused evacuations, closures, and reduced services, such as that seen in Puerto Rico and surrounding islands because of Hurricanes Irma and Maria 2017.

It is proposed that a partnership be established with collaborative public-private and community-based civil research, applications, and services agenda, to develop climate tools on the continuum from risk to resilience, which needs to include maintenance costs.

> "Regarding design and safety planning, to design hazard warnings, there exists an issue using static data for dynamic applications used for such planning."
>
> "Ultimately it is critical to build robust regional applications and networks to help guide practices, so that people know what to use and when, to mitigate risk. This is challenging because climate change planning is unstable in terms of probability, therefore one must acknowledge the cascading and compounding nature of systemic risk."
>
> *Roger Pulwarty*

2.4.2. Environmental Protection Agency

Mr. Vito Ilacqua

Research Scientist, Air Climate and Energy Program

National Center for Environmental Research

Dr. Ilacqua is a researcher in the Office of Radiation and Indoor Air at the Environmental Protection Agency and specializes in indoor air pollution, environmental epidemiology, pollution science, and risk assessment. His research focuses on the interaction of indoor and outdoor environments, and has contributed to the National Climate Health Assessment. He also oversees cutting-edge research on environmental health around the country, funded by EPA.

Climate Program at EPA and Public Health Implications of Climate Change and Buildings

Remarks

The Environmental Protection Agency has an acute interest in climate change, given the implications of climate impacts on public health. One unique area of research is the public health aspects of climate change and the intersection with building design.

The EPA has conducted research internally using statistical downscaling of global predictions, local conditions, and determining the most vulnerable communities and the causes of their vulnerability. Regarding building design, an external grant is currently looking at indoor air and climate change to understand the efficacy of retrofitting buildings to adapt them to climate change and/or be more efficient. More specifically, what would happen to the health of people living in such buildings. Results showed that most of the improvements had positive public health implications, which was not immediately intuitive.

Therefore, the EPA in collaboration with the colleagues at DOE Berkeley lab looked at a variety of possible impacts that can be anticipated. Beyond the public health perspective, the EPA also assesses a more insidious type of building damage that can occur from bad moisture management in building design.

There are specific climate tools developed by scientists at the EPA, including training and grants to help practitioners and decision makers. As an example, one can use these tools for community planning from the state, county, and city level to understand the impacts of changes in storm intensity. The tool can also be used by designers who might want different perspectives on the cost and investment of building a resilient home.

One of the most successful programs to date is the Indoor Air Plus initiative which not only helps improve indoor air quality, but also helps plan for indoor air quality in a changing climate. This program is being used by major national builders to design homes based on the Indoor Plus standards, which is like Energy STAR Homes, except that Indoor Plus focuses on the mitigation aspects of climate change and buildings.

Finally, the EPA has some involvement with building codes, and uses a voluntary consensus standard approach to foster more transparent and easily revised standards.

> "Considering buildings serve the purpose of protecting people from the natural environment (i.e., a shelter), most of the effects on climate change on public health will be through buildings and the effects climate change will have on buildings".
>
> "As an example, a researcher conducted contemporary analogues of future climates and found in one case study that in 2080 Washington D.C. would have a similar climate to that of the present-day climate between Arkansas and Mississippi. Knowing this type of information, one can then determine how to build a sustainable building fit for that type of climate."
>
> *Vito Ilacqua*

2.4.3. Lawrence Berkeley National Laboratory

Dr. Michael Wehner

Senior Scientist, Computational Research Division

Dr. Wehner's current research concerns the behavior of extreme weather events in a changing climate, especially heat waves, intense precipitation, drought and tropical cyclones. He is the author or co-author of over 200 scientific papers and reports and has served as lead author for both the 2013, 5th Assessment Report of the Intergovernmental Panel on Climate Change, and the 2nd, 3rd and 4th, US National Assessments on Climate Change, and is currently a lead author on the upcoming 6th Assessment Report of the Intergovernmental Panel on Climate Change.

Lessons Learned Communicating Climate Science with Decision Makers

Remarks

Communicating climate science to decision makers can be challenging, especially given the vast quantities of data available. This data can be very useful, but only if it's interpreted properly. Two examples are provided to illustrate this point.

> "Before beginning any project, one should ask 'Are the available datasets fit for the purpose at hand?' and oftentimes the answer will be no, however, by partnering with climate scientists, the data can be rescaled and assessed in a way that could provide useful results."
>
> *Michael Wehner*

The first example is a project funded by the San Francisco Public Utilities Commission is looking to design a new sewer system and decision makers need to determine the size of the pipes. Answering this question is complicated by rising sea levels, changes in precipitation patterns contributing to flash flooding, and the overall severity of storms. Those complicated scenarios are largely driven by climate change and can impact how well water moves down the pipes to prevent localized flooding. Given the scale needed to solve this problem, the global climate model data will need to be downscaled to provide useful information to decision makers involved in this project. For example, even the state-of-the-art supercomputers resolve multi decadal simulations of global warming at a resolution that is still five times the size of San Francisco. Statistically downscaling the climate data can provide fine scaled details, however it is important to make sure that the correct physical processes are being represented. With the help of colleagues at a third-party research firm, three hourly precipitation distributions were developed using statistical downscaling. The initial finding was that total storm precipitation lasted about three to four days, approximately a 6% increase per degree centigrade. However, this information isn't as useful to decision makers in determining the size of the pipes, and further research eventually arrived at results that could be applied to the pipe problem. Ultimately getting down to a high enough spatial and temporal resolution, they found that intense precipitation over a three-hour period increased to about 12 to 15 per cent per degree centigrade.

The second study, the Welder Project, looks to develop extreme weather metrics relevant to buildings. Unlike the pipe fitting problem, temperature can be analyzed at a lower resolution since temperature is relatively homogeneous at most scales. Results from a study looking at heating and cooling degree days in Fort Hood revealed up to two months of more days over 80 degrees by the middle of the century, under the "business as usual" RCP 8.5 climate change scenario. The study also showed that less heat and more cooling would be required in the future, which is relevant for various aspects of building design. What these projects demonstrate is that decisions about climate change should be a collaborative effort between decision makers and climate scientists. Otherwise, the climate data might be used improperly to fit the needs of the user.

2.4.4. U.S. Army Corps of Engineers

Dr. Jeff Arnold

Senior Scientist/Lead Climate Scientist

National Program Manager, USACE Climate Change Program

Dr. Arnold works on the technical and science-policy concerns of climate change for water resource applications around the world. He co-directs the USACE National Climate Preparedness and Resilience programs and leads the agency's integration of climate change mitigation with climate adaptation.

He leads the production of historical and projected future hydro-climatology for the Corps in close collaboration with federal labs, and university-based scientists.

Applications of Climate Change Information at USACE

Remarks

It is important to embrace the uncertainty of climate change to increase the robustness of the adaptation measures that are necessary to protect and build assets that can withstand the uncertainty of the future climate. Including climate information and building out assessments to allow operating engineers and planners to use that information is important for this process. They will be able to start those assessments and help establish baseline priorities to identify information that needs to be refined, applications that need further work, and more resources to get better answers.

Ultimately, all of this will contribute to more extensive training and capacity-building within and outside the Corps of Engineers to the wider climate hydrology community of practitioners. Although we can assess global averages to detect climate change signals, and we can see those signals and anomalies from what is known in the past to be large average conditions, it is impossible to use those global values for water storage and flux to understand hydroclimate conditions. Instead, we must look at smaller domains using those global scale anomalies to look for a climate signal.

> "A problem arises in those smaller domains where there exists a sizable gap between best climate science and the uncertainty in the science, and where the important questions need to be asked to use that information to increase resilience of existing or future assets."
>
> *Jeff Arnold*

To help bridge the gap, the Corp of Engineers developed guidance on how to use climate information for all their existing and future assets. This guidance is used to translate research, production, and implementation in their field office. A specific example for guidance for public use includes a tool for determining and understanding sea level change at any location, and then projecting that change in the future.

Model outputs and all observations used to develop all the Corp of Engineers Climate tools, including the model code itself, are publicly available. There are 30 terabytes of downscaled climatology to drive multiple hydrology models which also has about 25-30 terabytes of hydrology outputs to analyze future cases.

2.4.5. National Aeronautics and Space Administration

Dr. Michael Bosilovich

Research Scientist, NASA Global Modeling and Assimilation Office

PI for NASA National Climate Assessment Enabling Tools Project

Dr. Bosilovich specializes in Earth's water and energy cycles at the intersection of models and observations. He's also the principal investigator for the NASA National Climate Assessment Enabling Tools Project, which aims to facilitate the utilization of reanalysis data to address sector weather and climate data needs to bring new diagnostics and reanalysis data to bear on pertinent climate application issues.

Climate Tools and Applications at NASA GMAO

Remarks

The Modern-Era Retrospective analysis for Research and Applications (MERRA) reanalysis system assimilates 6 million observations every 6 hours. About 50 billion observations are included in the 40 years of data with over 300 variables available in the final output. The reanalysis combines observation data with an atmospheric model that provides the initial conditions for the forecast. This data assimilation method accounts for uncertainty of the model and the observations to create the reanalysis and produce a continuous global representation of weather and climate information.

MERRA-2 has also been applied to wind energy, building energy use, agriculture, and Famine Early Warning Systems. Because the data is generally coarse, it needs to be downscaled for those applications, and others like air quality, fire weather, and skin surface temperature to understand highway deterioration. Other diagnostics have also been developed such as building heating and cooling degree days.

> "MERRA and other satellite data have been formatted to use in various tools like GIS to help practitioners answer questions related to energy efficient buildings and agriculture. Another unique application of MERRA-2 data is by decision makers looking at changes in building zones and the relationship to the changing climate."
>
> *Michael Bosilovich*

Most recently MERRA-2 was used to compare daytime and night-time heatwaves, yielding counterintuitive results such as fewer daytime heatwaves than expected due to clouds, low precipitation, and a warm dry surface. Nighttime heat waves were shown to have varying characteristics depending on the location. The Midwest saw increases in precipitation, and more cloud coverage which acts as a blanket trapping warm air.

A final example evaluated extreme atmospheric rivers as they evolve. The researchers found differences in the moisture content in the air, and the atmospheric river, along with changes in the intensity of the synoptic weather patterns where lows were deeper and higher were higher, contributing to the observed increases in humidity.

Updates to MERRA-2 plans to increase the vertical resolution to improve data assimilation, a switch to all sky radiance to effectively use the maximum amount of observations, inclusion of atmospheric composition, and boundary layer, constant height data collection, which will be useful for wind energy products.

3. Conclusions

The workshop highlighted the needs, gaps, and opportunities for improved collaboration between building code and climate science researchers and practitioners as discussed in greater detail below.

3.1. Needs, Gaps, and Challenges

3.1.1. Developing climate projection data for building codes

- At present, forward-looking climate data addresses global climate-related questions and is not tailored to address building code concerns and data needs; climate spatial and temporal resolutions can be much larger than those needed for codes and standards.
- Specific climate data products for building codes need to be identified, such as projections for wind, snow, rain intensity, and flood elevations that include sea level rise.
- Building codes need climate projections at local scales to inform criteria for future building design and risk assessments. Consistent, standardized downscaling mechanisms are needed that are pertinent to the building code community, without losing key information from climate models.

3.1.2. Improving collaboration between building code and climate communities

- Development and adoption of guidance into standards and model codes can take a decade or more, followed by local adoption of model codes. There is an urgent need to start addressing climate issues for code adoption now.
- Clear guidance on information needed for an effective exchange between climate scientists and building code developers and users. This process could start with translating the information needs of the codes and standards community for guiding the climate science community.
- Potential issues need to be identified that may affect design practice using building codes when applying climate projections between regions and/or communities. National maps of natural hazards may be helpful in guiding this process.
- A summary of federal and state agencies and organizations that are sources or contributors to climate science and/or building codes would help clarify their respective roles.
- Leadership is needed to manage and advance the interaction between climate and building code communities by one or more agencies and/or organizations. This would include interactions between those responsible for sources of climate data and models, developing of codes and standards, and end users of climate information and codes.

- State and local groups need to be engaged to ensure that the national model codes have climate provisions that address their local needs.
- The US should learn from, and collaborate with, similar activities in other countries, including Canada, the European Union, New Zealand, and Australia.

3.1.3. A.3 Other issues critical to success

- Changes to building practices and their impact on climate changes should be addressed as part of the collaboration between climate and building code communities. Examples include the costs and benefits of mechanical and HVAC equipment, building envelopes, and structural systems that reduce carbon impacts.
- A number of complementary solutions need to be included for a comprehensive approach to future infrastructure performance and risks, such as land use policies, hazard maps, risk assessments, insurance, and insurability, equity, and vulnerable populations. Many times, those most affected by disasters or climate change are most at risk and are least financially capable of mitigating, adapting, or recovering. Land-use policies are needed for sea level rise, increased precipitation, drought, and other climate impacted hazard events. Insurance companies could develop strategies and finance mechanisms to address climate risks.
- Public education and awareness of climate impacts on communities are needed for improved understanding and awareness of changing risks to communities and infrastructure from future climate impacts.

3.2. Next Steps

Given the lead time for developing science and implementing it in guidance, standards, and codes, it is time to act now to link forward-looking climate data with codes and standards for resilient buildings and infrastructure. Climate change is already straining existing infrastructure and building codes do not currently account for climate change effects. Code updates need to consider both structural integrity and building performance to achieve community resilience and enable rapid recovery of infrastructure functionality. Interactions between the climate and building code researchers and developers, both public and private, need to be managed and facilitated. For a productive collaboration, the following series of steps will be necessary with a long-term focus because of the years-to-decades it takes to develop and adopt codes and standards:

- Convene a consortium of stakeholders and partners to lead and guide climate and code collaborations. Stakeholders include developers and users of climate information and codes and standards. Partners include national and international experts that can help advance climate science and its implementation. The US should learn from and collaborate with organizations conducting similar activities in other countries, including Canada, the European Union, New Zealand, and Australia.

- Produce a framework with a timeline for short- and long-term efforts to identify climate information needs by codes and standards organizations and what is available from current and emerging models. A summary list of federal and state agencies and organizations that are sources of or contributors to climate science and/or building codes would provide insight into their respective roles.

- Conduct a series of coordinated efforts, such as workshops, seminars, publications, data sets, and guidance documents, by climate and code communities to specify available climate information and gaps, including spatial/temporal scales and associated uncertainties, for codes and standards. The data types and quality may vary between products that support GHG emissions, weather events (e.g., precipitation and wind), wildfires, sea level rise, and other climate-related effects on buildings and infrastructure.

- Refine the framework based on the abovementioned activities and include timelines for developing climate information that can be used by codes and SDOs. For example, climate information may include future hazard projections for floods due to sea level rise or changes in precipitation due to changes in atmospheric and ocean temperature.

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A.1. Appendix A. Additional Perspectives and Documents

In addition to the presentations made during the workshop, participants were invited to submit perspectives and/or information on the workshop topic. The following submissions were received.

A.1.1. Thoughts on codes, standards, and climate change

By John L. Ingargiola, Lead Physical Scientist, Building Sciences Branch of the Risk Management Directorate at the Federal Emergency Management Agency's (FEMA) & Federal Insurance & Mitigation Administration (FIMA).

- Standards and codes should be developed holistically. If flood provisions of the codes focus on large commercial and nonresidential buildings first, it could encourage residential construction in floodplains. More restrictions on nonresidential buildings alone will encourage construction outside of the floodplain, especially of residential buildings such as single-family buildings in areas no longer considered viable for nonresidential construction. Building and residential codes should be considered simultaneously to avoid this problem.
- Suppose freeboard continues to be incorporated into the flood requirements. In that case, it should be recognized that every foot of the freeboard provides a different amount of protection depending on the floodplain characteristics. As more information becomes available using probabilistic flood risk datasets, the building requirements should reflect the probability of flooding over time. More mapping products will need to be made available to designers for the determination of minimum elevation requirements. Communities should be setting minimum elevation requirements based on the probability of various building types flooding and convey that information in a publicly available geolocated dataset.
- More maps or design tools are needed to address changes in precipitation rates over time. Explore how those changes in precipitation change flood risk.
- More tools are needed in coastal areas to address both existing and future flood risks. Besides addressing flood heights (at different recurrence intervals), depth, velocity, wave heights (at different recurrence intervals), and erosion risk must be considered. These variables will help designers be more successful at designing buildings.
- More work is needed on adaptive strategies: meaning either doing partial mitigation today with an ability to do more mitigation at a later date or potentially constructing buildings so that they could be mitigated at a future date. We need to consider that if climate change is of a greater magnitude than society has planned for, we could easily retrofit buildings to address the new risk. Codes should incorporate adaptive foundations and other adaptive building elements so buildings can be more easily mitigated.
- More tools are needed to support new engineering standards, such as ASCE 7-22 flood standards that will help building designers to be successful. Whatever is developed needs

to be accurate from the coastal engineers' perspective and must be easily understood and applicable for most building designers. From the standpoint of training and dissemination to building code users, today's engineering standards are more focused on precision in the writing of standards (e.g., wind, flood, seismic, etc.) but less focused on their usability by building designers. Even if it is a more conservative design, resiliency needs to focus on the everyday practitioner being successful instead of just focusing on the results' precision.

- Studies by FEMA Building Science indicate that nonresidential buildings located in Zone A and Coastal A Zones, when exposed to even a low sea level rise scenario, may have damages increased by at least 20%. Under higher rise scenarios, the losses may be 60% greater over the next 25 years when compared to current loss estimates and would double over the next 50 years. When evaluating areas in Zone V, this would be significantly higher.
- Advancing the resilience of the nation's building codes and standards with more climate science carries great importance but so does the adoption and enforcement of the codes we have in effect today. These codes are disaster-resistant and proven to save lives and reduce damage in numerous studies. Sadly, 2/3rds of the nation's jurisdictions subject to 1 or more natural hazards, DO NOT HAVE these recent codes in place. Until that changes, new codes that are developed with climate science incorporated will mostly sit on the shelf. Meanwhile, over 1 million new buildings are constructed every year and without adherence to minimum, consensus, disaster-resistant codes, this unfortunately ensures the rising cost and risk of future damages is almost certain. We have to stop this trend because of its devastating consequences to our future. Until such time as we have a true baseline of all jurisdictions having adopted and enforcing the latest consensus codes and standards, then we cannot build on top of that or get very far with selective adoption or very few numbers of communities or designers using these codes as a part of normal everyday business.
- One place to start is updating the minimum flood design and construction standards of the National Flood Insurance Program, which have not changed since they were created in 1968. Today, the ASCE 24 Flood Design and Construction Minimum Standard is the State-of-the-art voluntary, private-sector consensus minimum standard and is incorporated by reference into the International Codes. ASCE 24 contains numerous higher standards in comparison to NFIP. All communities, especially those vulnerable communities in the NFIP, should be afforded the minimum protection coming from the standards in ASCE 24 instead of the 52-year old minimum standards of the NFIP.

A.1.2. About the Global Resilience Dialogue International Survey

By Judy Zakreski, Vice President of Global Services International Code Council.

Global Resiliency Dialogue releases 2021 report detailing consideration of climate risk in building codes. This paper reports the findings of an international survey about how building codes around the world use climate data to address hazards and developed by the founding members of the Global Resiliency Dialogue–the Australian Building Codes Board, the National

Research Council of Canada, the New Zealand Ministry of Business, Innovation, and Employment, and the International Code Council (based in the United States).

The survey, which was circulated to building code development and research organizations around the world, was meant to help illuminate – in detail – how climate-based risks are currently considered within national building codes and standards. It included an exploration of the types of codes (building, fire, energy, electrical, plumbing, etc.) that rely on climate-related data to support their requirements, as well as the source of that climate data, how it is communicated, and how often it is updated.

The survey also explored the relationship between expected building life and climate projections, property protection versus life safety, land use/planning/zoning in relation to future-looking hazard assessments, and existing research related to building codes and climate-related risk.

A follow-on survey of building code stakeholders from the participating countries will focus on potential strategies to incorporate future-focused climate risk in codes and standards and the research needed for effective implementation. The results of this second survey will be presented in an additional report. Together, these two reports will inform the development of international resilience guidelines and joint research initiatives.

The findings shared in this paper indicate that the expectation of building resiliency to future weather events is largely based on historical data related to natural hazards, such as flooding, high wind, wildfire, and extreme heat, rather than on predictive data about the hazards that buildings are likely to face in the future. While some codes have begun to integrate forward-looking climate science to define select hazard measurements, these remain the exception with many questions still surrounding how to most effectively integrate appropriate climate science data into building codes. The findings support the work program defined by the Global Resiliency Dialogue and the likely relevance of the international resiliency guidelines that comprise the main deliverable of the group's work.

The whole document is available at the following ICC link:

https://www.iccsafe.org/wp-content/uploads/21-19612_CORP_CANZUS_Survey_Whitepaper_RPT_FINAL_HIRES.pdf

A.1.3. Additional Information about the Global Resilience Dialogue

By Judy Zakreski, Vice President of Global Services International Code Council.

The Global Resiliency Dialogue is an effort initiated by building code development and research organizations in the U.S., Canada, Australia and New Zealand that established in 2019 to work collaboratively to establish a pathway to the integration of climate science into building codes – in fact the very subject that was addressed throughout today's workshop. The website that we have set up to house the findings of the Global Resiliency Dialogue is https://www.iccsafe.org/advocacy/global-resiliency/.

To date, we have undertaken a survey to determine whether and how forward-looking climate data is used in advanced building codes around the world. We published the findings from that survey in a report entitled "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" at https://www.iccsafe.org/wp-content/uploads/21-19612_CORP_CANZUS_Survey_Whitepaper_RPT_FINAL_HIRES.pdf .

We are also in the process of conducting a second survey about what is needed – aspirationally – to effectively integrate climate science into building codes.

Based on the results of these surveys, we will be preparing an international resiliency guideline, which, in the U.S., can form the basis of an overlay document (a standard or a guideline) that can be adopted alongside the International Codes by communities wanting to address future climate risk, or that can be used to factor climate change into custom codes. We invite the SDO and government participants in today's workshop to sign onto the Global Resiliency Dialogue and work collectively with us on the international guideline.

The goal of creating an international resiliency guideline is to harness the best practices and research from around the world, particularly in countries that are ahead of the U.S. in addressing climate change in building safety. It will also provide a platform for joint research initiatives, particularly in areas of need identified through the second survey and/or in the process of drafting the guideline.

A.1.4. About Climate-Resilience Infrastructure

By Bilal M. Ayyub and Alice C. Hill: Climate-Resilient Infrastructure: Engineering and Policy Perspectives

Responding to natural disasters is a major challenge. Long-lived infrastructure must be resilient to the effects of climate change including weather extremes and other hazards. Infrastructure development requires a broad range of actors, including policymakers, planners, funders, engineers, researchers, and communities. Together they have shaped the physical structures and services intended to provide critical support to the public for decades. Despite that the uncertainties in the projections of the future climate obtained from climate models are not completely quantifiable, engineers are using risk-based adaptive procedures in order to close the gap between the characterization of climate uncertainty and the design of climate-resilient infrastructure.

Coordination between policy and engineering practice is necessary to achieve cost-effective solutions such as climate-resilient infrastructures that can face climate change conditions and extremes. Such coordination will depend on changes in the current practices of policymakers, planners, and designers.

The whole document is available at the following NAE link:

https://www.nae.edu/212185/ClimateResilient-Infrastructure-Engineering-and-Policy-Perspectives

A.1.5. About Adapting Infrastructure and Civil Engineering Practice

By Rolf Olfson and coauthors, 2015: Adapting Infrastructure and Civil Engineering Practice to a Changing Climate.

Engineering practices and standards are intended to provide acceptably low risks of failures regarding functionality, durability and safety over the service lives of infrastructure systems and facilities. Infrastructure is expected to remain functional, durable and safe for long service lives, typically 50 to more than 100 years. They are exposed to, and potentially vulnerable to, the effects and extremes of climate and weather (e.g., droughts, floods, heat waves, high winds, storm surges, fires and accumulated ice and snow) under conditions of a changing climate with heightened frequency and intensity of extreme events than in the past. The requirement that engineering infrastructure meets future needs and the uncertainty of future climate at the scale of the majority of engineering projects leads to a dilemma for practicing engineers. This dilemma is a gap between climate science and engineering practice that must be bridged.

This gap can be bridged by characterizing and quantifying (to the degree possible) uncertainty in future climate and taking such findings into consideration when planning and designing infrastructure. Engineers can attempt to make plans and designs adaptable to a range of future conditions of climate, weather, extreme events and societal needs for infrastructure. However, there will be a tradeoff between the cost of increasing system reliability and the potential cost and consequences of potential failure.

The following recommendations are appropriate:

- Engineers should engage in cooperative research involving scientists from across many disciplines to gain an adequate, probabilistic understanding of the magnitudes of future extremes and their consequences.
- Practicing engineers, project stakeholders, policy makers and decision makers should be informed about the uncertainty in projecting future climate and the reasons for the uncertainty, as elucidated by the climate science community.
- Engineers should develop a new paradigm for engineering practice in a world in which climate is changing, but cannot be projected with a high degree of certainty. When it is not possible to fully define and estimate the risks and potential costs of a project and reduce the uncertainty in the timeframe in which action should be taken, engineers should use low-regret, adaptive strategies such as the observational method to make a project more resilient to future climate and weather extremes.
- Critical infrastructure that is most threatened by changing climate in a given region should be identified, and decision makers and the public should be made aware of this assessment. An engineering-economic evaluation of the costs and benefits of strategies for resilience of critical infrastructure at national, state and local levels should be undertaken.

The whole document is available at the ASCE link:

https://ascelibrary.org/doi/book/10.1061/9780784479193

A.1.6. About the Impacts of Future Weather and Climate

By Mari Tye and coauthors: The Impacts of Future Weather and Climate Extremes on United States' Infrastructure: Assessing and Prioritizing Adaptation Actions (https://ascelibrary.org/doi/abs/10.1061/9780784415863).

This White Paper aims to build on the fundamental knowledge presented by previous ASCE publications. It summarizes the likely changes in various extreme meteorological and hydrological events and assesses the vulnerabilities of critical sectors, and their collective interdependencies, to the negative impacts of said events. In addition, a review is made about the frameworks that decision-makers can use to prioritize limited budgetary resources for adaptation efforts. This paper considers both acute vulnerabilities and responses (e.g. immediate consequences from a hurricane) and the chronic vulnerability to climate change. The authors' assessment for the most critical sectors (needed to support a functional society) are summarized below.

Energy (transmission, storage and distribution): This sector is considered ill prepared to cope with the effects of climate change. In particular, electricity generation will be affected by extreme temperature, precipitation and wind, and will suffer decreased efficiency as temperatures rise. Demand for electricity is expected to simultaneously increase significantly in the future due to increased cooling demands, increased population, and a growing number of electric vehicles on the road. Due to its interdependency with all other critical infrastructure, energy infrastructure is characterized as extremely critical with regard to its need for adaptation actions.

Transportation (roads, bridges, transit, and aviation): Coupled with the aging and deteriorating infrastructure network, its location generally in flat low-lying areas heightens transportation exposure and sensitivity to disruptive weather and changing climatic conditions. As with the energy sector, transportation is highly interlinked with other sectors, often providing critical support routes for evacuation and reconstruction activities. Vulnerability studies to date have focused on individual assets rather than the full network and the associated costs of replacement, but not indirect costs from avoided disruptions. The lack of redundancy in all transportation forms makes this sector particularly vulnerable to disruptive weather events that exceed design conditions.

Water and wastewater: drinking and wastewater systems are aging and increasing in fragility. Their location near rivers and coasts makes them highly exposed to flooding from fluvial, pluvial and tidal sources, and the attendant effects on water quality. While current risk of failure is moderate, due to built-in adaptive capacity, this will increase in the future without changes to current management practices. Available potable water in regions where reservoir systems were built to leverage seasonal snowmelt will also likely be affected by changes in precipitation cycles. Given the fundamental importance of water and wastewater, future changes in the climate together with increased demand and changes in consumption (e.g., arising from changes in population, industrial or agricultural demands) will result in severe impacts in the event of a loss.

Flood protection infrastructure (levees, flood barriers, dams, and reservoirs): While dam and reservoir operations are fairly responsive to precipitation variability under current river management practice, water supply is sensitive to future changes in precipitation patterns and the adequacy of storage. Projected changes in precipitation and temperature are likely to increase reservoir sedimentation and decrease water quality, as well as compromise dam structural integrity. The ramifications of dam, levee, or other flood barrier failure are considerable due to the levels of population and infrastructure protected. With many dams and levees having exceeded their design life, failures may occur unless monitoring is increased, and safety and maintenance standards are revised.

Navigation (inland waterways, port and harbors): Inland navigation is currently more vulnerable to lock failure than to climate extremes. However, competition for water supply during periods of drought may increase the frequency of extended low-flow induced closures. The impacts of port closures are largely economic and experienced by shippers. However, more frequent or extended closures could exceed the spare capacity in the transportation network with further reaching consequences on, e.g., food imports. Port infrastructure is at high risk of closures from coastal storms and sea level rise. In particular the supporting infrastructure, such as energy supplies and land transportation, will affect ports' ability to function in the future.

Not only is there a need to improve the capacity for emergency response and speed up the recovery process, it is also necessary to consider the major capital investments that could avoid interruptions of essential services. Recent disasters have emphasized that the loss of energy, transportation and telecommunications affect day-to-day life and have short and long term economic consequences. But over a longer timeframe, major disruptions, such as a loss of water supply due to increased droughts, reduced groundwater, or less snowpack, will have irretrievable consequences that can be avoided or mitigated by taking action now and by properly prioritizing those actions.

A.1.7. About Resilient Technology

By Albert J. Slap, Coastal Risk Consulting in "The Invading Sea": Resilient technology in identification of risks in commercial buildings

Resilient technology' can help owners of commercial real estate quickly identify risks and develop ways to address them.

The 2008 housing market collapse and the current COVID crisis show that our society and economic systems are fragile.

Resilient Technology can work very well when the underlying assets are damaged or shut down for lengthy repairs because of floods, natural hazards, and climate threats.

From 2017 to 2019, the U.S. experienced a historic number of weather and climate disasters. They included droughts, floods, freezes, severe storms, tropical cyclones and wildfires. The cumulative cost of these disasters exceeded $450 billion, a significant increase from earlier in the decade, according to NOAA.

The frequency and severity of these disasters is expected to continue to increase, according to the U.S. National Climate Assessment.

And according to Munich Re's 2020 Catastrophe Report: Global losses from natural disasters in 2020 came to $210 billion. The report also said that both "overall losses and insured losses were significantly higher than in the previous year."

There is evidence that commercial properties owners who fail to take action to improve the resilience of their facilities are susceptible to financial risks that may far surpass the costs of using resilience measures upfront.

Building owners are beginning to understand that improving resilience is not just a best practice, but a growing requirement to preserve the value of their assets, protect occupants, and attract investments. This is particularly true in risk-prone regions vulnerable to sea-level rise or wildfires.

For every dollar invested in climate resilience, $6 are saved, according to such organizations as the U.S. National Institute of Standards and Technology.

"Resilience is emerging as a critical issue for commercial building owners, particularly in light of recent disruptions from climate and weather events. Owners and operators of commercial buildings are placing a greater emphasis on improving the resilience of their assets and mitigating risk from natural disaster shocks and stressors," according to the U.S. Department of Energy's "Building the Financial Business Case for Resilience."

U.S. society is very complex, and, unfortunately, much too fragile. We have recently seen what happens when compounding challenges come along and our economic system goes into a nosedive.

In 2008's sub-prime mortgage crisis, the housing market crashed and the world slid into a global recession. In 2020, a microscopic virus — COVID-19 — brought a much larger wrecking ball to our shores. In many areas, 2020's hurricanes, floods and wildfires added to the COVID damage.

Resilient technologies, or as Nicholas Nassim Taleb would say, "antifragile" technologies, are the way of the future. These technologies are the path forward for commercial real estate to make their assets safer, more sustainable, resilient, and more profitable.

The entire note is available at the following The Inviding Sea site:

https://www.theinvadingsea.com/2021/01/26/resilient-technology-can-help-owners-of-commercial-real-estate-quickly-identify-risks-and-develop-ways-to-address-them

A.1.8. Resources from AIA

By Rachel Minnery, FAIA LEEDap, Sr. Director, Resilience, Adaptation and Disaster Assistance

The following documents reference the work of the American Institute of Architects work on climate adaptation, and related to codes. This is a small subset of our work on this topic, but a good starting place. If I can be of further assistance, please let me know. Thank you for putting together this terrific workshop.

Education and Resources

- AIAU Resilience and Adaptation Certificate Series- for architects and building industry professionals
  - Course 3 Responding to Climate Change
  - Course 4 Codes and Rating Systems for Resilience

- What Architects Need to Know About Climate and Hazard Risk
- Climate Adaptation Design Resources
- Hazard Mitigation Design Resources
- How to Integrate Resilience Into Your Practice

AIA Policy documents

- The American Institute of Architects – Climate Action Plan
- The American Institute of Architects- Code of Ethics (excerpt below)

  E.S. 6.5 Climate Change: Members should incorporate adaptation strategies with their clients to anticipate extreme weather events and minimize adverse effects on the environment, economy and public health.
- The American Institute of Architects- Policy and Position Statements
- Resilience and Adaptation excerpt, page 14:

  "The AIA supports policies, programs, and practices that promote adaptable and resilient buildings and communities. Buildings and communities are subjected to destructive forces from natural and human-caused hazards such as fire, earthquakes, flooding, sea level rise, tornadoes, tsunamis, severe weather, and even intentional attack. The forces affecting the built environment are evolving with climate change, environmental degradation, population growth, and migration; this alters long term conditions and demands design innovation. Architects design environments that reduce harm and property damage, adapt to evolving conditions, and more readily, effectively and efficiently recover from adverse events. Additionally, the AIA supports member training and active involvement in disaster assistance efforts, providing valuable insights and aid to communities before, during, and after a destructive event."

A.2. Appendix B. Climate Data and Tools

A primary source of climate data is NOAA's Climate.gov website: https://www.climate.gov
Additional sources of climate data, tools, and information include the following:

A.2.1. NOAA:

- National Centers for Environmental Information (NCEI, formerly NCDC):
  - https://www.ncdc.noaa.gov/climate-information
  - https://www.ncdc.noaa.gov/customer-support/tools
- Regional Climate Centers:
  - https://www.ncdc.noaa.gov/customer-support/partnerships/regional-climate-centers
- Regional Climate Services Directors:
  - https://www.ncdc.noaa.gov/rcsd
- National Weather Service (NWS):
  Climate Services Division:
  - https://www.weather.gov/climateservices
- Weather-Ready Nation:
  - https://www.weather.gov/wrn
- Climate Prediction Center (CPC):
  - https://www.cpc.ncep.noaa.gov
- Climate Program Office (CPO):
  - https://www.climate.gov/author/us-climate-resilience-toolkit
- Climate and Societal Interactions:
  - https://cpo.noaa.gov/Meet-the-Divisions/Climate-and-Societal-Interactions
  - https://cpo.noaa.gov/Serving-Society/NIHHIS
- National Integrated Drought information System (NIDIS):
  - https://www.drought.gov
- National Ocean Service (NOS):
  Office for Coastal Management:
  - https://coast.noaa.gov
  - https://tidesandcurrents.noaa.gov
- Performance, Risk and Social Science Office:

  - https://www.performance.noaa.gov/economics

A.2.2. EPA Environmental topics:

- https://www.epa.gov/environmental-topics

A.2.3. U.S. Army Corps of Engineers, Climate Preparedness and Resilience:

- https://www.usace.army.mil/corpsclimate

A.2.4. NASA's Global Modeling and Assimilation Office (GMAO)

- The Modern-Era Retrospective analysis for Research and Applications (MERRA) data set:
  - https://gmao.gsfc.nasa.gov/reanalysis
  - https://fluid.nccs.nasa.gov/reanalysis
- Solar and meteorological data:
  - https://power.larc.nasa.gov
- Applied Science, NASA's interagency partnerships:
  - https://science.gsfc.nasa.gov/610/applied-sciences

A.3. Appendix C. Agenda

NIST Workshop on

Incorporating Climate Change Data in U.S. Building Codes and Standards

10:00 am	James Olthoff NIST	*Welcome, Workshop Objectives, Logistics*
10:15 am – 10:30 am	Congressman Matt Cartwright	Opening Remarks: *Goals and Legislation*
10:30 am – 10:55 am	Alice Hill Council on Foreign Relations	*Building in a Changing Climate*
10:55 am- 11:20 am	Michael Kuperberg DOE	*Q & A Moderator*
11:20 am – 11:30 am	Zoubir Lounis NRC, Canada and Francis Zwiers Univ. of Victoria	*Overview of Canada's Initiative on Climate-Resilient Buildings and Core Public Infrastructure*
11:30 am – Noon		BREAK
12:00 pm – 1:30 pm	Panel presentations (15 minutes each)	*Building Codes Panel – Overview of Standards Developing Organization (SDO) Needs for Climate Change Data*: Panelists from building code, standards, and state/local organizations involved in code adoption/enforcement define what they need, when they need it, and in what form would be most useful.
	Dominic Sims	CEO, International Code Council
	Jennifer Jurado	Chief Resilience Officer, Broward County, FL

1:30 pm – 2:00 pm	Don Scott Birgitte Messerschmidt Dru Crawley Ann Kosmal Gordon Guillerman Therese McAllister NIST	Senior Principal, PCS Structural Solutions (ASCE 7 Wind Load Chair, Codes/Standards Activities Chair) Director of Applied Research, National Fire Protection Association Director of Building Performance Research with Bentley Systems Inc (ASHRAE) Architect, Strategic Risk Management & Resilience, GSA *Moderated discussion on climate change data needs in building codes and standards*
2:00 pm – 2:15 pm		BREAK
2:15 pm – 3:30 pm	Panel Presentations (15 minutes each)	*Climate Change Data Panel – Overview of Available Climate Change Data, Tools for SDO*: *Panelists from* Federal Agencies and NGOs will summarize data, models, tools, and reports available from their agencies and organizations for SDO use.
	Roger Pulwarty	Senior Scientist, National Oceanic and Atmospheric Administration (NOAA)
	Vito Ilacqua	Environmental Protection Agency (EPA)
	Michael Wehner	Senior Staff Scientist, Lawrence Berkeley National Laboratory
	Jeff Arnold	Lead Climate Scientist, U.S. Army Engineer Climate Preparedness and Resilience Program
	Mike Bosilovich	Research Scientist, National Aeronautics and Space Administration (NASA)
3:30 pm – 4:00 pm	Scott Weaver NIST Claudia Nierenberg NOAA	*Moderated discussion on available climate change data, models, and tools for development of building codes and standards*
4:00 pm –		BREAK

4:10 pm		
4:10 pm – 4:25 pm	James Whetstone NIST	Gaps Discussion
4:25 pm 4:45 pm	Jason Averill NIST	Summary of identified gaps, needs, and future actions

A.4. Appendix D. Video Recording of Presentations

All workshop presentations were video recorded after obtaining permission from the presenters. The workshop sessions were recorded in separate videos, all archived at NIST. To facilitate viewing, the initial and final time stamps of each talk within each session is noted below.

Plenary Talks

https://www.nist.gov/video/climate-science-and-building-codes-workshop-overview-and-plenary-talks

1.	James Olthoff:	00hr00min01sec – 00hr08min48sec
2.	Congressman Matt Cartwright:	00hr08min48sec – 00hr26min23sec
3.	Alice Hill	
	Introduction by M. Kuperberg:	00hr26min23sec – 00hr28min15sec
	Alice Hill's presentation:	00hr28min15sec – 00hr56min57sec
	Q&A:	00hr56min57sec – 01hr17min04sec
4.	The Canadian Experience	
	Introduction by T. McAllister:	01hr17min10sec – 01hr19min18sec
	Zoubir Lounis' presentation:	01hr19min18sec – 01hr27min08sec
	Francis Zwiers' presentation:	01hr27min08sec – 01hr37min10sec

Building Codes Panel

https://www.nist.gov/video/climate-science-and-building-codes-workshop-building-codes-and-standards-panel

1.	Introduction to the Panel by T. McAllister:	00hr00min01sec – 00hr00min35sec
2.	Dominic Sims:	
	Introduction by G. Guillerman:	00hr00min35sec – 00hr01min12sec
	Presentation:	00hr01min12sec – 00hr11min15sec
3.	Jennifer Jurado	
	Introduction by T. McAllister	00hr11min15sec – 00hr12min21sec
	Presentation:	00hr12min21sec – 00hr28min55sec
4.	Don Scott	
	Introduction by T. McAllister:	00hr28min55sec – 00hr30min06sec
	Presentation:	00hr30min06sec – 00hr45min31sec

5. Birgitte Messerschmidt
   - Introduction by G. Guillerman: 00hr45min31sec – 00hr46min27sec
   - Presentation: 00hr46min27sec – 01hr00min05sec
6. Dru Crawley
   - Introduction by T. McAllister: 01hr00min20sec – 01hr01min05sec
   - Presentation: 01hr01min05sec – 01hr13min00sec
7. Ann Kosmal
   - Introduction by G. Guillerman: 01hr13min00sec – 01hr13min42sec
   - Presentation: 01hr13min42sec – 01hr25min15sec
8. Panel Discussion: 01hr25min15sec – 01hr58min00sec

Climate Change Data Panel

https://www.nist.gov/video/climate-science-and-building-codes-workshop-climate-science-panel

1. Introduction to the Panel by S. Weaver: 00hr00min01sec – 00hr01min00sec
2. Roger Pulwarty
   - Introduction by S. Weaver: 00hr01min00sec – 00hr01min48sec
   - Presentation: 00hr01min48sec – 00hr18min40sec
3. Vito Ilacqua
   - Introduction by C. Nirenberg: 00hr18min40sec – 00hr19min10sec
   - Presentation: 00hr19min10sec – 00hr35min18sec
4. Michael Wehner:
   - Introduction by S. Weaver: 00hr35min18sec – 00hr36min12sec
   - Presentation: 00hr36min12sec – 00hr50min02sec
5. Jeff Arnold
   - Introduction by C. Nirenberg: 00hr50min02sec – 00hr50min51sec
   - Presentation: 00hr50min51sec – 01hr06min50sec
6. Mike Bosilovich
   - Introduction by S. Weaver: 01hr06min50sec – 01hr07min30sec
   - Presentation: 01hr07min30sec – 01hr20min54sec
7. Panel Discussion: 01hr20min54sec – 01hr49min19sec

Workshop Summary, Gaps and Next Steps

https://www.nist.gov/video/climate-science-and-building-codes-workshop-workshop-summary

1.	Introduction to the Summary by J. Averill	00hr00min01sec – 00hr01min30sec
2.	James Whetstone on Gaps	00hr01min30sec – 00hr08min38sec
3.	Jason Averill on Next Steps	00hr08min38sec – 00hr18min25sec

A.5. Appendix E. List of Registered Participants

First Name	Last Name	Organization
Linda	Acierto	NIST Congressional and Legislative Affairs Office
Christopher	Ackerman	Millennium Challenge Corporation(mcc.gov)
Peter	Adams	NYC Mayor's Office of Resiliency
Stuart	Adams	STANTEC
Helen	Amos	NASA
Allison	Anderson	Unabridged Architecture
Jeff	Arnold	US Army Engineer Climate Change Programs
Ahmed	Attar	Codes Canada, National Research Council Canada
Jason	Averill	NIST- Engineering Laboratory
Monica	Bansal	US Agency for International Development
Janice	Barnes	Climate Adaptation Partners
Brian	Blackmon	City of Knoxville, TN
Gopinath	Boray	HHS/ASA
Michael	Bosilovich	NASA GSFC GMAO Code 610.1
Steve	Bowen	Aon
Catherine	Broad	U.S. Department of Agriculture Office of Property and Environmental Management
Rodney	Bryant	NIST- Engineering Laboratory
Nelson	Bryner	NIST- Engineering Laboratory
Diana	Burk	New Building Institute
Dave	Butry	NIST
Phil	Calvin	Citizens Bank
Scott	Campbell	National Ready Mixed Concrete Association
Anthony Christopher	Cerino	STV/NCSEA
Laura	Champion	ASCE
Joseph	Chappell	FEMA
Joannie	Chin	NIST
Chris	Clavin	NIST- Engineering Laboratory
Ryan	Colker	International Code Council

David	Collins	The Preview Group
Emil	Consolacion	NAVFAC Atlantic
Curtis	Craven	US Navy
Drury	Crawley	Bentley Systems, Inc.
Andrew	Crees	CSA Group
Ray	Daddazio	Thornton Tomasetti
Samantha	Danchuk	Broward County, FL
Maria	Dillard	NIST- Engineering Laboratory
Kirk	Dohne	NIST
Jazalyn	Dukes	NIST- Engineering Laboratory
Dat	Duthinh	NIST
Amal	El Akkraoui	NASA GSFC
Andrew	Elken	????
Bruce	Ellingwood	Colorado State University – Civil Engineering
Dan	Eschenasy	City of New York
Katie	Faith	City of Folly Beach, SC
Tom	Frank	E & E News
Mark	Franz	University of Maryland
Juan	Fung	NIST
Robert	Gilbert	The University of Texas at Austin
Robin	Gilliam	Federal Accounting Standards Advisory Board
Maeve	Givens	ICF
Catherine	Goggins	US House of Representatives
Jennifer	Goupil	Structural Engineering Institute of ASCE
Rose	Grant	Rose Grant Architectural Services, Inc.
Bo	Green	E. B. Green, Architect
David	Green	NASA HQ
Jonathan	Griffin	NIST- Directors Office
Michael	Grimm	FEMA HQ
Emily	Guglielmo	Martin/Martin
Gordon	Guillerman	NIST
Sara	Hamideh	Stony Brook University

Anthony	Hamins	NIST
Katherine	Hammack	GBCI
Megan	Hart	Aon
Monique	Head	University of Delaware
Bill	Healy	NIST
Jennifer	Helgeson	NIST- Engineering Laboratory
Liz	Henderson	Aon
Bridget	Herring	City of Ashville, NC
Rebecca	Hersher	NPR
Mat	Heyman	Impresa Management Solutions, LLC
Alice C.	Hill	Council on Foreign Relations
Maria	Honeycutt	NOAA Office for Coastal Management
Priyanka	Hooghan	US House of Representatives- Rep. Bobby Scott
Daniel	Horn	ESKW/A
Christina	Hudson	US Air Force
Vito	Ilacqua	EPA
John	Ingargiola	FEMA
Peter	Irwin	RWDI Group
Jo	Johnson	NIST
Jennifer	Jurado	Broward County, FL
Kevin	Jurrens	NIST- Engineering Laboratory
Sarah	Kapnick	NOAA GFDL
Jesse	Keenan	Tulane University
David	Keller	US Department of State
Dalia	Kirschbaum	NASA GSFC
Bob	Kopp	Rutgers University
Ann	Kosmal	GSA
Kenneth	Kunkel	North Carolina State University
Mike	Kuperberg	US Department of Energy, Office of Science
Meghan	Ladwig	US Senate- Sen. Tammy Baldwin
Frank	Lavelle	ARA
Marc	Levitan	NIST- Engineering Laboratory

Ting	Lin	Texas Tech University
Kevin	Lindley	Chatham County, NC
Lauren	Linsmayer	US House of Representatives
Eva	Lipiec	US Congressional Research Service
Fred	Lipschultz	US Global Change Research Program
Mike	Logar	FEMA
Zoubir	Lounis	National Research Council Canada
Sue Lani	Madsen	The Madsen Group
Hussam	Mahmoud	Colorado State University
Joe	Main	NIST
Julian	Mancini	US Department of State
Jeremy	Marcus	US House of Representatives- Rep. Matt Cartwright
Serena	Martinez	NIST
Jeremy	Martinich	EPA
Lisa	Matthiessen	Amazon
Terri	McAllister	NIST- Engineering Laboratory
Gary	McGavin	Pomona Department of Architecture
Nancy	Mcnabb	McNabb & Associates
Ricardo A.	Medina	Simpson Gumpertz & Heger
Kishor	Mehta	Texas Tech University
Amy	Mensch	NIST
Birgitte	Messerschmidt	NFPA
Rachel	Minnery	The American Institute of Architects
Judith	Mitrani-Reiser	NIST- Engineering Laboratory
Kevin	Moore	Simpson Gumpertz & Heger
Kathryn	Mozer	NOAA OAR
Andrew	Mundy	NIST
Dalia	Munenzon	One Architecture and Urbanism
Cartier	Murrill	NIST
Aron	Newman	NIST- Engineering Laboratory
Michael	Newman	Insurance Institute for Business & Home Safety
Lisa	Ng	NIST

Claudia	Nierenberg	NOAA Climate Program Office
Sumant	Nigam	University of Maryland
Sissy	Nikolaou	NIST- Engineering Laboratory
Jim	Olthoff	NIST
Jamie	Padgett	Rice University
Shane	Parson	AECOM
Andrew	Persily	NIST
Long	Phan	NIST- Engineering Laboratory
John	Pitts	US Department of State
Veronica	Pochet	Levin Porter Associates
Ana	Prados	University of Maryland Baltimore County
Kuldeep	Prasad	NIST
David	Prevatt	University of Florida
Roger	Pulwarty	NOAA
Cynthia	Rivas	NIST- Engineering Laboratory
Jane	Rohde	JSR Associates, Inc.
Alfredo	Ruiz-Barradas	University of Maryland
Zahraa	Saiyed	Scyma Consulting LLC
Costa	Samaras	Carnegie Mellon University
Jose Alberto	Sanchez	Tipping Structural Engineers
Gavin	Schmidt	NASA GSFC
Stephanie	Schollaert Uz	NASA GSFC
James	Schufreider	NIST- Directors Office
Peter	Schultz	ICF International
Don	Scott	PCS Structural Solutions
Pataya	Scott	FEMA
Robin	Seidel	Weston and Sampson
Paula	Shaw	US Air Force AFCEC
Dominic	Sims	International Code Council
Constadino (Gus)	Sirakis	City of New York
Albert	Slap	Coastal Risk Consulting, LLC, Fort Lauderdale, FL
Sarah	Slaughter	Built Environment Coalition

Kenneth	Snyder	NIST
Ruth	Solomon	US Government Accountability Office
Lauren	Sommer	NPR
Greg	Soules	McDermott International, Ltd
Paul	Stackhouse	NASA
Cassie	Steiner	US House of Representatives
Joe	Thompson	US Government Accountability Office
Marina	Timofeyeva	NOAA NWS
Tori	Tomiczek	US Naval Academy
Ana-Maria	Tomlinson	CSA Group
Mari	Tye	NCAR/ASCE
John W.	van de Lindt	Colorado State University – NIST COE
Peter J.	Vickery	Applied Research Associates Inc.
Meghan	Walsh	US Department of Agriculture
Al	Wavering	NIST
Scott	Weaver	NIST- Engineering Laboratory
Michael	Wehner	Lawrence Berkeley National Laboratory
James	Whetstone	NIST
Tamae Maeda	Wong	NIST Gaithersburg
Don	Wuebbles	University of Illinois
Jiann	Yang	NIST- Engineering Laboratory
Alice	Yates	ASHRAE
DongHun	Yeo	NIST- Engineering Laboratory
Judy	Zakreski	International Code Council
Francis	Zwiers	PCIC, University of Victoria

A.6. Glossary of Acronyms

AIA	American Institute of Architects
ANCR	Alliance for National and Community Resilience
ASCE	American Association of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society of Testing and Materials
BOCA	Building Off and Code Administration
CMIP	Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Downscaling Experiment
DOE	Department of Energy
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
H.R.	House of Representatives
IBC	International Building Code
ICBO	International Conference of Building Officials
ICC	International Code Council
ICCPC	International Code Council Performance Code for Buildings and Facilities
IEBC	International Existing Building Code
IFC	International Fire Code
IGCC	International Green Construction Code
IPCC	Intergovernmental Panel on Climate Change
IPMC	International Property Maintenance Code
IRC	International Residential Code
IZC	International Zoning Codes
GAO	U.S. Government Accountability Office
GHG	Greenhouse gases
GSA	U.S. General Services Administration
GSOD	Global Surface Summary of the Day
MitFLG	Mitigation Framework Leadership Group
NCA	National Climate Assessment
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center

NCEI	National Centers for Environmental Information
NFPA	National Fire Protection Association
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
S	Senate
SDO	Standards Development Organizations
SBCCI	Southern Building Code Conference
SES	Society for Standards Professionals
ULI	Urban Land Institute
USGCRP	U. S. Global Change Research Program
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Modelling
WMO	World Meteorological Organization