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A Conversation on Adaptation in the Built Environment

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A Conversation on Adaptation in the Built Environment

Editor's Note: To accompany the article "Understanding Climate Change Impacts on Building Energy Use," the authors, Arfa N. Aijazi, Student Member ASHRAE, Gail S. Brager, Ph.D., Fellow ASHRAE, and ASHRAE Journal moderated a roundtable discussion with experts in building and urban scale design, weather modeling/simulation, and buildings codes and standards development. For further reading on ASHRAE's position on climate change, the "ASHRAE Position Document on Climate Change" was revised by the Society's Climate Change Position Document Committee and approved by ASHRAE's Board of Directors in June. This is the sixth version of the position document since it was first created in 1992. The document is available at www.ashrae.org/about/position-documents.

Q1: What does climate change adaptation mean in your practice and how does it differ from sustainable design more broadly?

Wilhelm: Climate change adaptation impels us to create energy systems that are resilient to the challenges posed by climatic change. For example, more extreme heat days (as well as warm nights) compound the urban heat island effect, can strain the energy system to meet peak demand, and—in cases of grid outages—could create serious public health challenges (e.g., in senior residences). Other climate-related challenges that California's energy system, built environment, and infrastructure must grapple with include sea level rise; increases in frequency of wildfires as well as area burned, compounded by changes in wildfire behavior; changing precipitation patterns that suggest more frequent flooding *and* more severe dry spells. This differs from conventional notions of sustainable design that tend to be framed in terms of impacts to the environment, rather than impacts of the environment on a system.

Pyke: Climate change adaptation means anticipating and preparing for future climatic conditions. For me, this means using the best available scientific information to anticipate and prepare for the conditions a building is likely to experience over its performance lifetime. This is done to increase the likelihood that the

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building will meet performance expectations. Failure to anticipate and prepare for foreseeable future conditions is (1) negligent and (2) inconsistent with sustainable design. Consequently, I see climate change adaptation as one part of effective sustainable design.

Laxo: Sustainable design focuses on climate change mitigation: how can we design to minimize our contributions to climate change? Climate adaptation looks at the current science of climate change, recognizing that some amount of climate change is now irreversible and the uncertainty of future scenarios puts the design industry, and our clients, at risk. At my firm, we have begun to shift our practice to incorporate conversations around risk into our practice, evaluating the greatest climate change impacts to our clients and incorporating strategies to prepare their buildings for those potential future impacts.

Brashear: Climate change adaptation means designing our projects to function and serve people and the environment successfully into the future, even as our climate is changing and future temperatures, water levels, and a multitude of other features of our environment, are uncertain. The greatest difference between climate change adaptation and sustainable design is the element of uncertainty or change. In sustainable design, people usually look to "sustain" the quality or health of the environment. However, with climate change adaptation we can no longer assume that by sustaining the current condition of our environment that the environment or what we build will function the same way in the future. We must design for a changing condition and uncertain future.

Q2: Discuss a project where you considered climate change adaptation. What were some lessons learned?

Brashear: These days, we have to consider climate change in virtually all of our work. As an example, a great number of our landscape projects are on or near tidal waterfronts. These already dynamic places—where water levels rise and fall each day—are becoming more uncertain with sea level rise and increasing storm events. We have to design for future high tides which may be many feet higher than they are today and for more infrequent flood events that could inundate sites and buildings. The reality is that deciding how to adapt to rising sea levels requires weighing many subjective as well as objective factors—it is not a technical decision, but one that requires value judgements and balancing the needs and wants of different stakeholders; it is a difficult and complex process.

Roberts: My firm has documented over 20 case studies of the impacts of future climate data on buildings. A notable case study for the *ASHRAE Journal* was a study of Code Case Analysis for Title-24 in California. We assessed heat pump and insulation cost effectiveness shifts as a result of annual changes in energy consumption across multiple climate zones in California. The results showed that use of historic climate data may be locking in code measures that are less appropriate under future climate conditions and missing opportunities for inclusion of other code measures. A second notable case study focused on the selection of HVAC technology for a building retrofit. The results suggested value in small increases in trunk duct size and plant area for future cooling loads. The cost of upgrading the

> Climate change adaptation means anticipating and preparing for future climatic conditions. ~Chris Pyke, Ph.D.

trunk ductwork by 10% was insignificant on the project compared to the potential for failing to meet comfort conditions in future years (and having to retrofit at very high cost). The same study also suggested that the type of HVAC system may have been revised from four pipe VAV to air-to-water heat pump due to the change in heat/cooling energy balance over the year. A third notable case study on a district thermal energy system for a large university campus identified significant benefit of moving to heat recovery/heat pumping given the shift in energy balance in future years. Since the university had already decided to pursue a heat recovery system, they were reassured that the results suggested the system would increase in effectiveness in the future rather than lose effectiveness.

Tomlinson: One of my firm's recent LEED certified designs included natural ventilation. To meet the occupant comfort requirements set by ASHRAE Standard 55, occupants were provided with control of cross ventilation and ceiling fan speeds. This mechanical design significantly reduced the energy demand within the facility, mitigating climate change. However, during further assessment of the design using projected weather extremes, the summer's thermal conditions within the facility would not comply with ASHRAE Standard 55. We needed to advise the owner that the facility may eventually require air conditioning. As energy reduction was the primary goal of the project, air conditioning was not installed. Instead, the electrical panel was sized for potential future equipment loads. An unfortunate lesson learned is that today's climate change mitigation efforts may be reversed as climate changes increase cooling demand.

During a major renovation of a historic facility, WUFI [hygrothermal] models were run to examine various insulation options within the external wall assembly. Searching for projected weather files to match the WUFI inputs, it came to our understanding that the current statistical downscaled weather files do not provide the needed outputs. To meet this need, through the MN Resiliency Collaboration, we are now assessing viable dynamical downscaled climate model outputs, reliability and storage needs for design use.

Wilhelm: As a manager of energy-related environmental research grants at the California Energy Commission, many of the grants that I manage consider climate change adaptation. Among the lessons learned are that high-resolution (spatial, temporal) projections of future climate scenarios are imperative to enabling consideration of impacts of climate change on California's energy system with sufficient detail to clarify vulnerability and resilience options. Moreover, these downscaled projections must ably capture not just general trends and measures of central tendency, but the extreme events that drive the impacts of climate on people, economies, and infrastructure. Specifically, one project contributing to California's Fourth Climate Change Assessment (led by John Radke at UCB's Center for Catastrophic Risk Management) found that it was difficult to engage transportation fuel sector stakeholders in a discussion of risk until his research team was able to present results with sufficient resolution to inform potential impacts on their particular infrastructure and operations. This underscores a related notion in the public sphere, namely that for people to "connect" to climate change they must understand it in their personal, local context. Connecting climate change to the particular context of infrastructure, assets, and operations will be increasingly critical in fostering interest in and action on adaptation.

Laxo: Bringing a climate change adaptation perspective to the table on projects can be challenging, as it disrupts "best practice" in the architecture and engineering industry. Our clients are often not well-versed in current climate science, and we find ourselves balancing between sharing enough information to help them make decisions, and sharing too much that we overwhelm our clients. Client literacy is a great factor in determining how far we are able to dig into adaptation; with such a plethora of uncertain future results, we need to come to shared decisions with the client on how to plan for the future. Working with the GSA results in a very different process than private companies or smaller cities with no chief resilience officer. Our role has been informing, educating, and trying to meet our clients where they are, while helping them consider future climate risks when making design decisions.

Q3: How do you communicate uncertainty related to climate change to your clients? What are compelling ways to visualize for different audiences?

Rastogi: We communicate uncertainty in terms of risk, e.g., risk of overheating, risk of loads exceeding some threshold of unit costs, shift in percentile temperatures and its impact on load calculations, etc. Adding an "error bar" to a simulation output is often the simplest and most effective way of communicating/visualizing uncertainty, primarily because our clients are mostly familiar with them. Plotting probability distributions tends not to be as effective.

Brashear: We try to illustrate climate change as tangibly as possible, in language and graphics that relate the likely consequences of climate change to people's experiences. We try to connect predicted future climate events—high tides, storm surges, or rainfall events with associated flooding for instance—to events that people may have experienced in the past, translating future potential increases in intensity or frequency to something with which people are familiar. If there is no reference event, which is not uncommon given the nature of climate change, using local landmarks for elevation references or other disruptive events to understand potential impacts of future climate influenced events can help communicate future possible scenarios. For visualization, we develop simple, clear graphics to try to help unpack the "black box" of climate science, developing simple diagrams, plans, sections, or axonometric drawings to describe how climate change processes act on our built and natural environment.

Wilhelm: Cal-Adapt is, in ongoing development at UCB's Geospatial Innovation Facility and in collaboration with Eagle Rock Analytics, working to better portray climate variability as well as uncertainty associated with projected climate outcomes. Presently, the annual average precipitation and temperature tools portray uncertainty by presenting the "envelope" of 32 downscaled CMIP5 projections for whatever emissions scenario (RCP 4.5 or RCP 8.5) is chosen. The user can view one particular (or several) downscaled General Circulation Models (GCM), which shows as a colored line (time series) in the gray envelope associated with the ensemble of downscaled projections.

Huang: I think it's a shortcoming to present just the GCM results as if that's the only evidence of global climate change. We should also present the historical trends and how they align (or not) with the GCM results. To me, that would be much more compelling as well as show the level of uncertainty about the projections. Similarly, we could show the results from different GCMs projected over time. I've been working on that with another member, and it's been interesting.

Q4: What motivates you to consider climate change related risks in your projects? How does this rank in comparison to other project goals?

Roberts: My firm's motivation for early adoption has been our values, ethics, and intellectual curiosity. However, we are increasingly conscious of the move from voluntary action toward compelled action. In January 2018, the Conservation Law Foundation in Massachusetts changed the conversation by sharing their legal opinion that designers may have a legal liability for failing to act. My firm was among 30+ organizations consulted for their report (www.clf.org/wp-content/uploads/2018/01/GRC_CLF_Report_R8.pdf) in which CLF stated: "Failure to act in the face of climate risk could result in legal liability. ... prevailing practices... [and] explicit standards.... are not the only factors that determine legal responsibility for... failing to act reasonably in the face of ascertainable climate risk....obligations can be heightened when considerations of public health or safety are at issue." For example, "A building code may not require elevating mechanical equipment to the upper floors of a building. However, in a legal claim for damages, a court could still find that ascertainable flooding risks... compel this practice as the industry standard of care."

Tomlinson: An ethical practicing professional engineer must be dedicated to the protection of public health, safety and welfare. Professional engineers are also obligated to advise clients or employers when they believe a project will not be successful. Considering climate-change related risks in a design or engineering service is necessary to maintain the profession's highest standards. Professional licensed consultants must educate themselves on climate change and the risks it poses to their designs and advise their clients to the best of their ability.

As a commissioning process provider, project goals are identified and ranked through an owner's project requirements assessment. While a professional may advise a client, ultimately, the owner defines their project goals and priorities.

Brashear: We aim to consider climate change and climate change adaptation in all of our work. However, for any given project, the priority which this takes relative to other project goals and aspirations is ultimately up to the client. We can often identify co-benefits, where a climate change adaptation can achieve other project goals, save on long-term maintenance and operation costs, or provide educational opportunities or positive PR. This is not always the case though, and many climate adaptation measures can require up-front costs that can be difficult for clients to weigh against other project needs and priorities, particularly for often budget-constrained public works.

Pyke: First and foremost, I think it is clear that the best available science tells us that historic conditions have limited relevance to the conditions under which buildings will perform in the future. For me, this means that using historic conditions as the basis for the design of new buildings expected to perform for decades is wrong. We can have a reasonable, technical debate about how changing conditions should be addressed; given available scientific and technical understanding, the exclusive use of historic conditions is technically incorrect. We can and should anticipate changing conditions in our key design decisions—including the "typical" meteorological conditions, design storms, etc. This should not be something extra or novel. This is simply a logical and necessary extension to prevailing design practice.

Q5: Future weather projections have built-in uncertainty due to climate change scenario, weather forecasting, and future time-period, so how do you establish criteria for acceptable levels of risk? Is it always appropriate to design for the "worst-case" scenario?

Brashear: Establishing criteria for acceptable levels of risk requires clear communication of what is known (and not known) about exposure and vulnerability to hazards and the potential consequences to stakeholders, followed by a transparent dialogue about what level of risk is safe, people are willing to tolerate, and is feasible or affordable. It often is not appropriate, or feasible to design for the "worst-case" scenario, but it is important to understand the implications and potential consequences (residual risk) of designing to a less conservative prediction, as that may affect people's choices and decisions or trigger other design alternatives (including options like no action or retreat) to be considered.

Roberts: The answer depends on the client, but my firm encourages a three-step process: 1) stress testing using worst-case conditions at the end of useful life (which is often longer than design life). This can help an owner understand when their system will fail (if at all) and what the implications may be. 2) Cost vs benefit design optioneering. If there is a significant impact, then the owner can request the team assess options for addressing the impact based on design actions or alternative projected future climate considerations. For systems that are very high cost or for very significant impacts, this may become a fairly detailed probabilistic loss based analysis, but for most projects, it's simply tweaking the design a little and discussing future retrofit solutions that can defer the investment. Lastly 3), we suggest testing "current climate" weather files that are either recent AMY files or near future fTMY/design conditions to assess if some building systems are being unintentionally over-sized and can be reduced in size and scale to save the owner money.

Tomlinson: ASHRAE offers an Equipment Life Expectancy Chart to guide life-cycle decisions. Most mechanical systems on the chart average a 20-year life expectancy. This range of life expectancies indicates that most major mechanical systems will be replaced at some point during the life of a 50 to 100 year building. These anticipated system replacements can accommodate revised capacities due to changing climatic design requirements. However, weather file use in models impacts much more than mechanical systems. Energy and hygrothermal models guide envelope material selection and construction as well. Use of inaccurate weather files could lead to underperforming envelopes or building failures.

Is it necessary to design for the "worst-case" climate change scenario for every building? No. Critical infrastructure such as emergency operation centers, hospitals, energy, water and communications facilities may warrant or require 'worst-case' scenarios analysis. A building that does not impact public health, safety or welfare were it to remain out of use for an extended time period is not identified as high risk. A risk assessment of the specific project site will provide guidance on potential hazards, vulnerability, impacts and project priorities.

Wilhelm: As a research manager with the state of California, we consider both state guidance (e.g., the Ocean Protection Council's recently updated sea level rise guidance document) and current research (which can evolve at a faster clip than guidance documents, given the need for guidance to balance needs related to stakeholders' desires for stable guidance, policy processes, and scientific soundness).

Pyke: In most cases, we can bound a plausible range of future conditions for key parameters. We can use these bounds to modify traditional design parameters, e.g., heating and cooling degree days, design storms. Moreover, even very simple, modest adjustments to these parameters, such as those offered by tools like WeatherShift, are better than simply defaulting to historic conditions.

I would not risk making generalizations about "worst-case" scenarios, as this is consideration that each project team needs to make for itself based on the scope, budget, and goals of the building. However, more generally, current global trends in greenhouse gas emissions and climate change are consistent with the worst case scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). Consequently, with respect to the selection of climate scenarios, selecting the "worst-case scenario"— from those developed by IPCC—is scientifically justified.

Huang: What I don't like is creating extreme conditions by combining the worst case condition for each parameter (temperature, solar, wind), something the ASHRAE design condition is guilty of to a limited extent,

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because the probability of that occurring is unknown and likely to be extremely low.

Q6: The reliability of building simulations depends on many factors such as the quality and detail of the model itself and uncertainties connected to the choice of weather dataset. What do you think is a rough order of magnitude for uncertainty related to weather and how does this compare to other sources of uncertainty (e.g., occupant behavior, changes during construction, etc.)?

Crawley: Building energy use can vary as much as 20% to 30% in response to year-to-year weather variation. The usual weather that we use, TMY, typical meteorological years, are just that, an artificial year that gives roughly the median of the period of record. I believe that for building simulations we should not be using TMYs alone. We need to introduce more extreme weather into our calculations or we risk making decisions based on typical data, without understanding the implications.

Huang: I'd like to distinguish between uncertainty and variability. Uncertainty has to do with how true are the data with the actual conditions, while variability has to do with how much does the data change over time? In terms of weather data, if we're trying to calibrate a model against measured data, the uncertainty of that weather data is quite low, within a few percent provided that the weather station is of high quality. But in terms of using historical weather data such as "typical year" data for a different time period often in the future, the variability of weather data is a lot more and can easily be in the 10% to 20% range. Some 30 years ago (!), I did a study simulating a residential building with "typical year" and historical weather files for the past 25 years in 10 or so U.S. locations. The average deviation in space conditioning energy use for the latter compared to the former was between 8% to 12%. This is just stochastic variability. The variability over time due to heat islands and climate change tend to be uni-directional and can swamp that stochastic variability over a decade or two.

Rastogi: In our simulation-based investigations, we have found that buildings with small internal loads, passive features, or leaky envelopes tend to have ranges of two to three times the mean of the figure being considered. For example, peak loads or annual overheating hours in a warm summer in Europe can easily exceed two to three times the figures for a moderate summer. This is going to be exacerbated in the near future by the introduction of time-of-use tariffs, which will disproportionately penalize peak use. Then we can expect peak financial impacts to be easily 10 to 15 times higher. Uncertainty in characterizing occupant and equipment characteristics significantly outweighs climate in our client base for commercial and retail spaces. Retail spaces are dominated by specialized refrigeration and lighting, so getting those correct is paramount. Since many of our clients are financial firms, their offices tend to be dominated by screens and similar devices.

Q7: How can we validate simulation results from future weather projections? If we can't, how can we create more confidence in results?

Huang: Bluntly speaking, you can't, unless you were to wait another 30 years. And when that time comes, I would guess that all the projections would be wrong in detail, but not so in general. This is why I'm suggesting we also look at historical trends as another indicator of what the future weather would be.

Crawley: If we compare energy use when simulating one or more extreme years against modeled future years, we can get a sense if the future data invoke similar response in building performance - an extremely hot historical year vs. a future year.

Rastogi: We find that interest and confidence in the results of our simulations is improving with every previously unseen weather event. However, we have stopped pushing to validate estimates of extreme weather since, by definition, extreme values show up rarely, and in the absence of a perfect model of the global climate, predictions cannot be perfectly accurate. As part of increasing confidence in our results, the profession should stop pushing precise predictions. We have been working with clients to understand the concept of preparing for extreme weather and systematic climate change using the systems and language they have for other hard-to-predict factors such as fire and accidents. Most of our clients understand and work with risk every day, so we normally talk in terms of the expected values of events. That is, the preparation for an incident must consider both impact on human health or productivity and the probability of occurrence. We encourage clients to think in terms of adaptability, categorizing actions in terms of their impact and disruption, so that both building owners and their end-users can adapt to events of different severity.

Pyke: I would restructure the terms used in this question. Projection—or as it is used here, forecast—is a very special case for simulation. The implication here is that the goal is to accurately predict absolute building performance at some point years in the future. Weather is only one of many sources of uncertainty in such a forecast, and, personally, I see little benefit in honing our collective skills at multi-decadal building energy forecasting.

In most cases, we want to use scenario analysis to understand the sensitivity of performance outcomes to design choices—ideally choices where the design team has the ability to select among discrete alternatives to improve building performance. This is typically a choice about the relative cost and benefit of specific design choices, and this plays to the strength of current modeling tools.

In this context, we should be primarily concerned that models are consistent and results provide the right relative results. The current generation of models is entirely adequate to the task of understanding the consequences of past, present, and future weather, in the context of real-world variation in design, construction, and operation. We have the basic understanding needed to quantify plausible changes in temperature, storm intensity, humidity, and other factors. We have the software needed to look at the relative impact of these changes for different design options. We have the technology needed to measure real world performance and create iterative loops between design and outcomes. We appear to lack the will to use these tools confidently and appropriately on a large scale.

Q8: Why is there a lag in the building industry in using weather files other than typical meteorological year, namely extreme and future weather data?

Crawley: Historically, it has been a huge undertaking to create typical year data. To add future or extreme weather on top of that, until recently, has been difficult. Most simulation programs do not support multi-weather data sources. So it is up to the user to find and run multiple weather files and compare results. Unfortunately, many users accept whatever weather file is available without understanding its provenance or potential limitations.

Huang: In my opinion, the main reason for the hesitancy in using anything besides or beyond "typical year" weather data is the persistence to regard weather as long-term steady state. This leads to...a lack of concern about the vintage of the historical record. For example, the standard recommended period of record for developing a "typical year" weather file is 30 years. Add this to the fact that many of the "typical year" weather files that are still being used were created from 10 to 20 years ago. This means that most of them are capturing the average conditions from roughly 30 years in the past.

There is legitimate concern that future weather data generated from global climate models may not be reliable. However, there should be equal concern that using past weather data can also be problematic. There are also ways to bridge the gap by tweaking how the "typical year" weather data are created by (1) using a shorter and more current time period, and (2) taking the observed trends in the historical records in defining what would be the most “typical” conditions.

Pyke: This is a social, not a technical problem. Key industry standard setting bodies have been remarkably recalcitrant in incorporating the best available science into key codes and standards. We should have done this 10+ years ago. We could come to agreement on key operational assumptions very quickly provided there was sufficient will to act.

Roberts: I agree with Chris… the problem is not the value or quality of future climate data, as long as it’s peer reviewed and appropriately applied. The primary issue is lack of a suitable driver for uptake. When you are already working a 50 hour week, adding one more action, especially one that you don’t fully understand and have never tried before… that’s not a great recipe for change in practice. No one (has yet) been fired for failing to consider future climate in their building design. The reality is that the clients aren’t asking for it, the authorities having jurisdiction aren’t requiring it, and the third-party rating systems are not providing credit for it. There has been some debate within the future climate data community that has not been helpful in resolving forward action, but overall such debate is healthy in pointing the direction of ever-improving process and application. It’s much better that we constructively debate how to apply future climate data, not whether or not to do so. The perfect (future climate data) has sometimes been the enemy of the good (design for future climate).

Tomlinson: To meet the current professional engineering standard of care, engineers use verified and published climatic data based on observed historical measurements. There is a general professional understanding that “observed data” is more defensible than “projected model outputs.” However, as the World Federation of Engineering Organization wrote in their Model Code of Practice: Principles of Climate Change Adaptation for Engineers: “Reliance on codes, standards and professional guidelines that fail to reflect an understanding of the impact of climate change may not be sufficient to mitigate potential liability related to managing those impacts on professional work.”

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I do not see the building industry's lag in projected weather file use stemming from professional disinterest, but rather, from a systemic limitation. To date, there is no industry standard or authority on projected weather file use. Higher education institutions do not regularly incorporate climate science within engineering or architectural degrees, which limits professional competence to assess or use projected weather files. State licensing boards do not currently require continuing education or professional development in the field of climate science, which could be an extension of ethics. Also, case law has not yet assigned climate change adaptation liability to design professionals. Any one of these systemic limitations could change and the building industry's standard of care would follow suit. For now, non-historic weather file use is still an emerging market, dominated by innovators and early adaptors.

Laxo: We have been surprised by how few of our peers in the industry even realize that there is a problem with using historical weather data to inform design. Presenting to peers at local, regional, and national conferences, we often see shocked expressions when we connect the basic science behind climate change to why "best practice" is not, in fact, best practice. This is a large barrier to the adoption of seeking out and using future projections in the design process—lack of knowledge.

Rastogi: We think the lag is partly due to inertia, because the profession is familiar with the intuitive and simple concept of "typical" years, and partly due to the way simulation is currently used as a tool for relative comparisons or ranking options, i.e., it is not always the case that simulating with a variety of climate inputs will lead to a different answer than simulating with only a typical input. Replacing typical files with a single, or a small number, of future or extreme files does not address the problem of the lack of certainty. In most engineering calculations, when the operating conditions of a system are unknown, we seek to define a standard test set that has as much coverage as possible without being too onerous. However, the problem with future climate is that the number of possible paths or options is too vast to collapse into a simple and small set. We promote the use of many, varied samples to calculate a distribution of plausible outcomes.

Q9: What standards, guidelines, and codes are available regarding climate change adaptation?

Brashear: Many individual municipalities are developing climate resilience guidelines or integrating climate change adaptation guidance, particularly around flooding and sea level rise, into building and zoning codes. At the state level, a number of states have passed state level legislation to encourage or require counties and municipalities to begin to integrate climate adaptation into local plans, codes, and guidelines.

Roberts: The best U.S. guidelines (and mandatory action) to date is by the City of New York. My firm was a participant in finalizing the NY City Climate Resilience Design Guidelines and they are very good—addressing heat, rainfall, and sea level rise. They primarily serve to provide a common source of data and data applicability guidance along with definitions in process. They are an umbrella document under which various city departments are developing more detailed guidance. Currently, the NYC CRDG are mandated for all City-funded projects but are voluntary for private sector projects in the city. The State of California just completed the AB2800 Climate Safe Infrastructure Working Group, which has noted a need to bridge science and practice. Boston also has implemented guidance for sea level rise and rainfall. States and cities are taking the lead today, but where they go, the rest of development will eventually follow.

Crawley: All existing standards and guidelines have been based on measured data. This is probably due to the role that climate data has played in building design--design conditions for sizing and selecting HVAC equipment. As these are used in litigation and court cases, they have been based on measured conditions rather than modeled or future data (ASHRAE, CIBSE). One exception are the future climate data that CIBSE have produced for the UK.

Rastogi: In the UK we have the following publications from CIBSE to assess and address overheating risk in buildings: TM52, TM59, Guide A, and KS16.

Q10: How are your agencies supporting efforts to adapt to climate change?

Roberts: My firm's efforts go beyond supporting our own practice but are attempting to support the design industry broadly - our clients, collaborators, and competitors. To that end, we developed the first global dataset of future climate data in industry standard formats for heat and rainfall using peer reviewed methods and an ensemble of up to 27 global circulation models. We collaborated on the development with Argos Analytics, a climate science firm started by a senior author of the IPCC 5th assessment and climate scientists. The dataset at www.weathereshift.com can be used to generate future climate data for more than 10,000 cities globally across a distribution of up to 14 projected futures in any future year (typically 2030, 2060, 2090). In addition, we are developing global training modules for best practices in the application of Design for Future Climate across all of our disciplines—from building engineering to energy management to infrastructure development to policy and planning. As an employee owned company, we volunteer to provide input into emerging knowledge and we welcome collaborators and clients eager to safeguard the future of the built environment and the communities that call our cities and towns home.

Tomlinson: ASHRAE is committed to improving the resilience of our nation's buildings, infrastructure, public spaces and communities. The Society of ASHRAE efforts include:

- Uniting with dozens of other building industry leaders, ASHRAE committed to the Industry Statement on Resilience.
- Recently expanded the ASHRAE Position Document on Climate Change to include climate change adaptation commitments within our professional competence and expertise. These commitments include research and guidance of materials, design, construction, and operations of buildings and infrastructure to adapt to changing environments.
- Recently, the Society approved the creation of a new technical committee with a specific focus on resilience and security.

ASHRAE's Global Climate Change Technical Committee regularly collaborates with building industry leaders, expert climatologist and legal professionals to provide the most relevant climate change continuing education for our members. Most recently, topics have included resilient design lessons from past natural disasters, changing design requirements within city,

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state and federal levels, as well as, climate change design risks and liabilities.

Pyke: I work for the U.S. Green Building Council, a D.C.-based non-profit. We are working across three scales to promote climate adaptation—which we often included in a broader conversation about resilience:

(1) National, state, and local policy;

(2) Design, construction, and operation of green building projects (including spaces, buildings, neighborhoods, and cities); and

(3) Investment and management of property and infrastructure companies.

USGBC is working with allies to encourage national, state, and local policies to address the drivers of climate change and encourage adaptation. The USGBC Center for Resilience website provides an overview of advocacy activities at the federal, state, and local level, https://new.usgbc.org/center-for-resilience.

At the project scale, USGBC has been working to incorporate climate resilience into LEED and create an entirely new rating system dedicated to resilience called RELi.

At the company scale, USGBC is working closely with GRESB to create new tools to assess the resilience of property and infrastructure organizations. These efforts includes the development of a new Resilience Module aligned, in part, with recommendations from the Financial Stability Board's Task Force for Climate-Related Financial Disclosure.

Wilhelm: The California Energy Commission (CEC) has supported a suite of research projects that contributed to California's Fourth Climate Change Assessment (https://climateassessment.ca.gov/). CEC-supported work included climate projections (temperature, precipitation, sea level rise, wildfire, and more) as well as studies of vulnerability and resilience options in the energy sector. Since 2013, the Energy Commission's demand forecast office has been publishing decadal demand forecasts that use projected future, rather than historical, climate. Although the percentage change in projected peak demand may be small, the implications with regard to siting new generation sources in a fairly short timeframe are large. The 2016 update of the Integrated Energy Policy report delineated climate scenarios in response to the recommendation that: Energy research and planning, respectively, should use a common set of climate scenarios as selected by the Climate Action Team Research Working Group and the Governor's Office of Planning and Research Adaptation Technical Advisory Group.

Rastogi: Most authorities in the UK, at the regional and local levels, mandate reporting of climate-related risks. However, this is not necessarily augmented with capacity-building efforts everywhere. The Scottish government has an agency called Adaptation Scotland whose stated goal is to improve adaptation among organizations and communities by providing advice and support. Other examples include CIBSE, which publishes guidelines and methods, the Taskforce on Climate-related Financial Disclosures (TCFD), which has introduced standards on financial risk reporting, and the Meteorological Office, which supports professionals with climate modelling. ■

Roundtable

What topics would you like to see for future roundtables?

Send your suggestions to jayscott@ashrae.org