The Nexus of Building Energy Codes and Resilience

November 2024

United States Department of Energy
Washington, DC 20585

Executive Summary

Deadly disasters, such as the February 2021 Texas freeze, reveal the compound impacts extreme weather can impose when energy infrastructure is disrupted. Extreme weather—the primary driver of major power outages—poses a particular threat to the electric grid and the Nation's energy security at large.[1] The rising cost of disaster events exposes deeper vulnerabilities between buildings, community services, and the electric grid. As the U.S. faces the growing impacts of climate change and extreme weather, the need for resilience throughout the built environment becomes a national imperative.

Enhancing resilience throughout the built environment demands an integrated approach to address immediate and future climate risks. Buildings are a fundamental component to community resilience, enabling greater energy resilience for individual structures and the electric grid at large. This report evaluates the potential for building codes, particularly building energy codes and standards, to improve resilience outcomes in the built environment.

What is Energy Resilience?
Resilience is defined as, "the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events."[2] The resilience of a building is intrinsically tied to the availability of continuous power; disruptions to the electric grid compromise the critical services buildings provide over the course of an extreme weather event. Acknowledging this relationship, the report focuses on the *energy resilience* of buildings.

Energy resilience characterizes the ability to operate building energy services, such as heating, cooling, ventilation, critical electric plug loads, and shelter, during and in response to a major disruption. Building energy resilience is defined by two central functions, as captured in Table 1 below:

[1] U.S. Department of Homeland Security, *Climate Action Plan* (Washington, DC: DHS). 2021. p. 1. https://www.dhs.gov/sites/default/files/publications/21_1007_opa_climate-action-plan.pdf. Accessed March 1, 2023.
[2] National Research Council, *Disaster Resilience: A National Imperative* (Washington, DC: The National Academies Press). 2012. p. 16. https://nap.nationalacademies.org/download/13457. Accessed November 14, 2023.

Table 1: Primary Purpose of Building Energy Resilience

Passive Survivability	**Grid Resilience**
The ability to maintain safe indoor conditions in the event of extended energy outage or loss of energy supply. In practice, passive survivability enables safe indoor thermal conditions, relying on building design measures that require no energy. As a measure of a building's thermal performance, passive survivability offers an integrated assessment of both energy efficiency and resilience.	Building energy technologies that provide efficiency and grid flexibility services. These technologies can provide grid services during peak demand periods. Demand load reductions alleviate energy supply and grid constraints, thereby decreasing the risk of power system failures.

Energy resilience may also encapsulate secondary benefits, including improved comfort, safety, and health. Together, these benefits contribute to the broader resilience of a community.

The Role of Building Energy Codes

Building codes establish minimum design, construction, and performance requirements for multiple aspects of residential and commercial buildings, such as plumbing, electrical, fire safety, and energy performance. A key function of codes is to mitigate property damage and protect occupant life and safety. Building codes account for numerous hazards, such as those related to wind and snow loads or fire and moisture resistance. Building codes are widely recognized as a core requisite of community resilience, yet less than half of jurisdictions have adopted hazard-resistant codes.[3]

To address this gap and the rising cost of disaster events, the 2018 Disaster Recovery and Reform Act (DRRA) reoriented Federal disaster funds towards mitigation-based work centered on the adoption the latest International Building Code (IBC) and International Residential Code building code editions.[4,5] In addition, new energy code funding through the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA)[6] is expected to increase resilience through support for building energy codes, including code adoption, implementation, and compliance processes throughout the country. BIL Section 40511 specifies several related activities, such as workforce development and training, compliance research, and energy code planning and implementation, as well as many other activities which ensure resilience, health

---

[3] Federal Emergency Management Agency, *Building Codes Save: A Nationwide Study of Loss Prevention.* (Washington DC: FEMA). 2020. https://www.fema.gov/sites/default/files/2020-11/fema_building-codes-save_study.pdf. Accessed March 1, 2023.

[4] U.S. Congress, House Committee on Appropriations, *Energy and Water Development Appropriations Bill*. Report 116-102 to accompany S. 2470, 116th Congress, 1st session, September 12, 2019. p. 88. https://www.congress.gov/116/crpt/srpt102/CRPT-116srpt102.pdf. Accessed November 14, 2023.

[5] The International Code Council (ICC) is responsible for administering the IRC and IBC. Further explanation of the code development process is provided in later sections.

[6] *See* BIL Section 40511 and IRA Section 50131

and safety in residential and commercial buildings. Over $1.2 billion in new Federal funding is available for energy code support through the Department of Energy, which can help support states and jurisdictions in achieving a more efficient and resilient building stock.[7] [8]

Building codes are a widely recognized policy instrument to address the emergence of new and elevated natural hazards risks to the built environment. Updated every three years, Federal, state, and municipal governments can readily adopt the latest *model* code editions that incorporate improved technologies and design practices. Codes are typically coordinated with related industry standards, meet established criteria such as technological feasibility and cost effectiveness, and are familiar to the insurance sector. Modern building codes contain numerous provisions that bolster resistance to natural hazards and extreme weather. To account for the changing conditions future weather and climate hazards present, building codes must continue to evolve.

Energy codes are a subset of building codes that set minimum requirements for building energy performance and efficiency measures.[9] They address specific building design components, including insulation, windows, building envelope air leakage, and heating, ventilation, and air conditioning (HVAC) systems. Energy codes primarily ensure sensible and cost-effective efficiency measures are included in construction, but also offer additional guidance that supports occupant comfort, health, and safety. Model building energy codes are updated through established consensus processes, administered by organizations such as the International Code Council (ICC) and American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), and published triennially. Energy codes are adopted in some form across every U.S. state,[10] and are implemented by state and local governments.

It is recommended states and jurisdictions adopt the energy model code outright. In practice, state and local code adoption bodies commonly amend the model codes, often removing measures that support efficiency and resiliency. Even after a code is adopted, code compliance professionals require education and training, as do designers, builders, contractors, and a range of affected stakeholders. These three aspects of the code process—development, adoption, and compliance—are critical to ensure that the many benefits of energy codes—increased energy efficiency and environmental benefits, health and life-safety, and resilience—are realized in U.S. homes and businesses.

[7] DOE EERE Building Energy Codes Program, *Resilient and Efficient Codes Implementation*, https://www.energycodes.gov/RECI. Accessed March 29, 2024.
[8] DOE State and Community Energy Programs, *Technical Assistance for the Adoption of Building Energy Codes*, https://www.energy.gov/scep/technical-assistance-adoption-building-energy-codes. Accessed March 29, 2024.
[9] Model energy codes for residential buildings are part of the International Energy Conservation Code (IECC), maintained by IECC and by ASHRAE for commercial buildings.
[10] Department of Energy, Building Energy Codes Program, "Status of State Energy Code Adoption." https://www.energycodes.gov/adoption/states. Accessed March 1, 2023.

While energy codes do not set explicit resilience criteria, they provide inherent resilience benefits.[11] Building envelope requirements, designed to minimize heating and cooling demand, support passive survivability outcomes. When energy delivery is interrupted, buildings that meet higher building envelope standards are better equipped to maintain safe conditions during a heat wave or cold snap. Energy codes not only improve grid resilience through energy efficiency but include provisions that enable grid-interactivity. These provisions cover such features as demand responsive controls and appliances, occupancy sensors, building energy management systems, and battery storage.

The latest model energy codes also offer an alternative performance-based compliance pathway that utilizes a time-based utility rate. Such compliance pathways enable more integrated approaches to building design and provide greater benefits to the grid than traditional energy code requirements. Yet energy codes still only consider building energy performance under “normal” conditions.[12] The evolution of codes to support energy reliability and grid resilience must address the associated risks and trade-offs that occur when power is disrupted. For example, states and jurisdictions could consider expanding the scope of energy codes beyond efficiency requirements to also establish thermal resilience criteria.[13] The final section of this report highlights the Building Technologies Office (BTO) efforts to establish energy code energy resilience requirements through the code development process.

How Building Energy Efficiency Strategies Can Enhance Resilience

Building efficiency measures and energy technologies can help contribute to broader resilience outcomes beyond energy codes’ domain, bolstering capacity before, during, and after a disruptive event. As previously highlighted, energy resilient buildings primarily play a key role in promoting grid resilience and mitigating the risk of more consequential power disruptions. In turn, efficient buildings provide a range of ancillary benefits to enhance community resilience at large.

---

[11] Other types of building codes may provide more direct resilience requirement, such as the National Fire Protection Association (NFPA) code that requires some building types (e.g. hospitals) to install onsite backup power system(s).

[12]Rodney Sobin, Ed Carley, Carl Blumstein, David Hungerford, Laura Van Wie McGrory, and Jeffrey Harris Carr, “Energy Efficiency is not Enough.” ACEEE Summer Study of Energy Efficiency in Buildings. 2018. p. 11-6. https://www.naseo.org/data/sites/1/documents/publications/Energy%20Efficiency%20is%20Not%20Enough-%20Rethinking%20Building%20Energy%20Performance%20for%20Good%20Times%20and%20Bad.pdf. Accessed November 14, 2023.

[13] Kesik, Ted, William O'Brien, and Aylin Ozkan. “Towards a Standardized Framework for Thermal Resilience Modeling and Analysis.” *ASHRAE Topical Conference Proceedings*. American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., 2020. p. 65. https://www.ashrae.org/file%20library/conferences/specialty%20conferences/2020%20building%20performance/papers/d-bsc20-c008.pdf. Accessed November 14, 2023.

The resilience of the electrical grid is paramount to the Nation's health, security, and economy.[14] Extreme weather can trigger failures within energy supply chains, disable energy generation capacity, and lead to supply-demand imbalances, placing excess stress on infrastructure. Grid-interactive efficient buildings (GEBs) are energy efficient buildings equipped with smart technologies that can optimize energy use for grid services to mitigate further disruptions.[15] GEB technologies, such as smart thermostats and heat pump water heaters, provide demand flexibility during peak demand or constrained periods.

When extreme temperature events coincide with power or fuel energy loss, the risk to building occupants sharply increases. Insulation, efficient windows, envelope air tightness, and passive ventilation can prolong comfortable indoor temperature conditions during a power outage. Efficient buildings, particularly when combined with a backup power or energy storage systems, are better equipped to function, and maintain operability under such conditions. Together, these efficiency measures enable buildings' passive survivability.

Beyond grid resilience and passive survivability, energy efficient buildings provide a variety of additional benefits to individual buildings and the surrounding community. Energy efficiency measures, such as high-performance windows, insulation, and moisture-management strategies can also increase buildings' structural integrity and durability. Combined with proper ventilation techniques, energy efficient designs can mitigate indoor air contaminants from the outside environment. Similar strategies can reduce the potential for mold growth and other lasting moisture damage, especially after an extreme temperature event. Additional benefits are presented in later sections of this report.

While there are numerous building technologies and design strategies that can satisfy the same efficiency target, these design choices may have a variety of consequences for energy resilience. As with all building design, energy resilience strategies will vary by climate region, building type, occupant needs, and local infrastructure systems. In addition, the increase in compounding disaster events (e.g., when two or more hazards occur at the same time or in close succession to one another) introduces more complex risks into building design and community resilience.

While many energy efficiency strategies can enhance resilience outcomes (e.g., resistance to extreme temperatures or providing the ability to shelter in place during a disaster event), in some cases energy efficiency and resilience may produce conflicting outcomes. For example, energy efficiency measures such as thicker insulation and tighter building envelopes can decrease drying potential following a flood event. Windows with high solar heat gain coefficients (SHGC) reduce winter heating loads but could exacerbate indoor temperatures

[14] National Academies of Sciences, Engineering, and Medicine, *Enhancing the Resilience of the Nation's Electricity System* (Washington, DC: The National Academies Press). 2017. p. 8. https://doi.org/10.17226/24836. Accessed November 14, 2023.
[15] U.S. Department of Energy, *A National Roadmap for Grid-Interactive Efficient Buildings*. (2021). p. 3. https://doi.org/10.2172/1784302. Accessed November 14, 2023.

during a summer outage event. More research is needed to better characterize and evaluate these types of interactions between different building technologies and identify the optimal combinations of advanced technologies that provide both energy efficiency and resilience.

The U.S. Department of Energy (DOE) BTO is supporting research examining the nexus of building energy efficiency and resilience. Several of BTO's current efforts are presented in Section 6. In addition, BTO coordinated with the Oak Ridge National Laboratory (ORNL) to host a workshop that evaluated the relationship between efficiency and resilience and identified critical challenges and gaps in the current body of knowledge. A diverse group of industry experts and stakeholders identified several important findings, particularly the need for additional metrics and technical analysis that can be used to define and quantify energy-resilience impacts and inform decisions regarding future research and development (R&D). The findings of this workshop are further discussed in Section 2.

Key Research Findings for Energy Resilience

In researching the role of building energy codes and energy efficiency strategies in enhancing resilience, BTO assembled a list of key findings for policymakers and the broader building design and construction industry to consider in prioritizing efforts supporting enhanced energy resilience. These findings are presented below, with individual concepts emerging from BTO's review of the current body of knowledge, including research conducted by others; prominent policies and programs supporting enhanced resilience, such as DRRA; related programs supported by the Federal Emergency Management Agency and Department of Housing and Urban Development; and state and local community resilience plans. Key findings are also supported by BTO's own programming, including findings of the ORNL workshop, and insight from ongoing research such as BTO's core R&D on emerging technologies, and by way of applied research programs such as Building America.

Based on current research, BTO observes the following key findings targeting enhanced energy resilience in buildings:

1. **Current building codes are a critical prerequisite to achieving energy resilience**. Recent Federal policy updates, most notably DRRA, identify model building codes and standards as the cornerstone for strengthening the resilience of any community. The latest building codes, such as the IBC and the IRC, contain numerous provisions intended to achieve minimum levels of resilience, updated each cycle to bolster resistance against natural hazards such as flooding, hurricane winds, earthquakes, and tornados. Yet only about half of the jurisdictions located in a high-risk region have adopted hazard-resistant codes. To encourage greater adoption and enforcement, Federal mitigation efforts are beginning to incorporate incentives and program requirements. Additional work is underway to support building resilience through more holistic approaches. Prominent codes and standards development bodies, including both the ICC and ASHRAE, are developing performance goals and supporting strategies that bridge modern building codes with other community-level

policies. Such efforts can further orient energy resilience within community-wide planning.

2. **Model energy codes can further evolve to support energy resilience**.
The ICC and other leading organizations acknowledge model energy codes as a necessary part of a coordinated, code-based approach to community resilience. While energy codes are primarily developed to set energy efficiency requirements, they include key provisions that support building energy resilience. The increase in extreme weather events presents emerging risks for the development of resilient building codes. Energy codes will likely serve a more critical role within hazard-resistant building design to address the growing impacts of extreme temperatures. Energy codes further support broader resilience objectives between buildings and energy infrastructure. These considerations would require establishing new methods, standards, and assumptions to assess building energy resilience within model energy codes.

3. **Improved analytical methods are needed to assess the full range of resilience benefits**.
Accepted metrics and methods for evaluating energy efficiency benefits are commonplace, typically reported as impacts on energy use (e.g., EUI), cost (e.g., return on investment) or equivalent environmental impacts (e.g., tonnage of CO_2). In considering potential code changes, code development and consensus bodies such as the ICC typically require statements attesting to expected energy and cost impacts. Such benefits are generally accepted as quantifiable and reasonably certain for decision-making purposes. However, many resilience benefits are risk-based, intended to mitigate, or prevent damages associated with hazards or system malfunctions, and when successful may avoid such damages altogether. Resilience benefits are challenging to assess, and particularly quantify, if the current criteria required to support proposed code changes are used. In addition, resilience benefits often extend beyond the building alone, as is the case with building-grid integration and connected HVAC systems, which mitigate peak demands on the utility grid. Traditional analytical methods used to assess energy efficiency do not currently capture the true impacts of these connected systems, and new methods are needed to quantify time-sensitive impacts on energy use and efficiency.

4. **Energy efficiency programs are starting to prioritize resilience**.
Billions of dollars are spent each year to upgrade and harden the grid through investments in transmission and distribution infrastructure. While local governments often lead in planning for “disaster preparedness, climate adaptation, and community resilience,” some utilities and public utility commissions are also starting to embrace demand-side management as a method to address the reliability and

resilience of the electric grid.[16] Traditionally focused on total energy savings, emerging efficiency programs offerings are now often designed to target peak demand periods, which enhances resilience and reliability by lowering grid stress from high peak demand. Efficiency programs span a broad range of offerings from new construction to retrofits, behavioral innervations, or specific technologies such as heat pump water heaters and combined heat and power (CHP) systems. These strategies reflect the increasing role of building energy systems as a distributed energy resource (DER).

5. **Building technology R&D can continue to prioritize energy resilience.**
   Technology-based R&D initiatives by DOE and others have led to several advances, helping increase resilience through energy efficiency technologies. BTO-supported R&D spans early-stage and applied R&D, to validation, demonstration, and commercialization, to technical analysis supporting industry standardization and widespread technology adoption. Enhancing energy resilience in buildings is a multifaceted problem, from traditional efficiency technologies that save energy and cut waste, to improving building material performance and increasing durability, to "smarter" systems with the ability to shift, shed, and modulate energy consumption to support enhanced grid and power system reliability. The interdependencies of efficiency technologies and practices are complex, particularly when coupled with the goal of enhancing resilience. BTO and others can continue to support technology R&D, including new and advanced technologies, which yield energy-resilience benefits, explore integration challenges, develop metrics and methods to adequately quantify energy-resilience impacts, and address barriers to their commercialization and acceptance in the market.

While not a comprehensive list, each of the above trends reflects prevailing efforts to enact energy resilience within the built environment. These trends are discussed in more detail throughout the report along with specific strategies, associated challenges, and current activities to enhance resilience within buildings. Specific needs for R&D are also addressed, with an emphasis on technical analysis and stakeholder engagement, followed by recommendations for further study.

[16] Dan York, Brendon Baatz, and David Ribeiro, "The Role of Electric Utility Energy Efficiency Programs in Building Community Resilience." ACEEE Summer Study of Energy Efficiency in Buildings. 2016. p. 11-8. https://www.aceee.org/files/proceedings/2016/data/papers/11_366.pdf. Accessed November 14, 2023.

The Nexus of Building Energy Codes and Resilience

Table of Contents

I. Introduction

The greatest consequences of disasters are often the result of disruptions triggered by the initial physical event itself. In February 2021, Winter Storm Uri set off power system failures in Texas, exposing buildings—many of which were ill-equipped to withstand such conditions— to the outside environment. The drop in indoor temperatures led to consequential occupant health outcomes and significant property damage, primarily driven by frozen pipes. Texas authorities reported that, as of October 27, 2021, 246 deaths are linked to the winter storm blackout in Texas.[17] Direct damages totaled $20 billion across Texas and several surrounding states, making it the costliest winter disaster event in U.S. history.[18]

Winter Storm Uri revealed a new paradigm in disasters: the compounding of extreme events. Compound events—a combination of multiple hazards, disruptions, and/or extremes—account for the growing impacts of disasters.[19] The physical and socioeconomic impacts of the Texas winter storm were significantly amplified by the widespread blackouts, the result of cascading failures across Texas' energy infrastructure system.[20] As shown in Figure 1, the increase in major disaster events coincides with power disruptions. Disasters expose interdependencies between buildings, critical infrastructure, and the broader community; resiliency solutions must address how risk scale across the various systems that connect the built environment.

[17] Texas Department of State Health Service, "February 2021 Winter Storm-Related Deaths – Texas," December 31, 2021. p. 2. https://www.dshs.texas.gov/sites/default/files/news/updates/SMOC_FebWinterStorm_MortalitySurvReport_12-30-21.pdf. Accessed March 7, 2024.

[18] National Oceanic and Atmospheric Administration, "*2021 U.S. billion-dollar weather and climate disasters in historical context*," March 17, 2022. https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical. Accessed April 11, 2022.

[19] Field, Christopher B., et al., eds. *Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change*. p. 27Cambridge University Press, 2012. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf. Accessed March 11, 2022.

[20] Busby, Joshua W., et al. "Cascading risks: Understanding the 2021 winter blackout in Texas." *Energy Research & Social Science* 77 (2021): 102106. pp.2-4

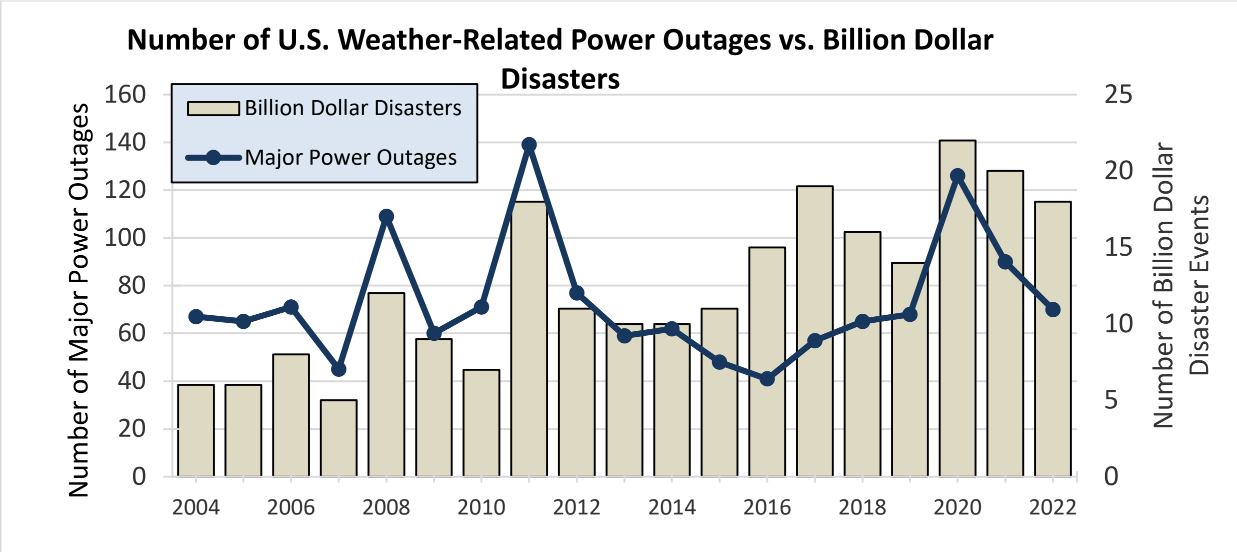

Figure 1: Number of US weather-related power outages and billion-dollar disaster events.

Source: Billion Dollar Disaster data,[21] power outage data[22]

[21] U.S. Department of Commerce, NOAA National Centers for Environmental Information "Billion-Dollar Weather and Climate Disasters: Overview." 2023. https://www.ncdc.noaa.gov/billions/. Accessed May 30, 2023.
[22] U.S. Department of Energy, Office of Cybersecurity, Energy Security, and Emergency Response, Electric Disturbance Events (OE-417) Annual Summaries. https://www.oe.netl.doe.gov/OE417_annual_summary.aspx. Accessed March 11, 2022.

Examples of Recent Disasters Where Power Loss Led to Consequential Outcomes

- **Extreme weather events can render energy infrastructure inoperable far beyond the initial disaster**. In 2017, Hurricane Maria hit Puerto Rico as a Category 4 hurricane, causing damages that would leave the island without full power for 11 months.[23] In recognition of dependencies between buildings, the grid, and energy supply, Puerto Rico's recovery proposals include rebuilding through more energy-efficient, resilient building design.[24]

- **The intersection of compound extreme events presents new resilience challenges.** During the 2020 summer, California faced simultaneous extreme events: an unprecedented heat wave that contributed to a record-setting wildfire season,[25] the coronavirus pandemic,[26] and rolling power outages.[27] Normal practices to reduce indoor air temperatures and improve indoor air quality were compromised, as air-conditioning was unavailable and windows were not safe to open due to wildfire smoke.

- **Forced outages are used to mitigate damage caused by aging grid infrastructure during adverse weather conditions.** After a series of wildfires sparked by power lines in California, Pacific Gas and Electric Co (PG&E) staged precautionary blackouts to deal with wildfire risk in October 2019. Over 967,000 customers went an average of 55 hours without power.[28]

---

[23] Department of Homeland Security, The President's National Infrastructure Advisory Council, "Surviving a Catastrophic Power Outage: Increasing the Capabilities of the Nation." December 2018. https://www.cisa.gov/sites/default/files/publications/NIAC%20Catastrophic%20Power%20Outage%20Study_FINAL.pdf. Accessed March 11, 2022.

[24] Commonwealth of Puerto Rico, Central Office of Recovery, Reconstruction, and Resiliency, "Transformation and Innovation in the Wake of Devastation: An Economic and Disaster Recovery Plan for Puerto Rico." p. 67. August 8, 2018. https://prsciencetrust.org/wp-content/uploads/2019/01/pr-transformation-innovation-plan.pdf. Accessed March 11, 2022.

[25] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73.

[26] "Excess of COVID-19 Cases and Deaths due to Fine Particulate Matter Exposure During the 2020 Wildfires in the United States," Xiaodan Zhou, Kevin Josey, Leila Kamareddine, Miah C. Caine, Tianjia Liu, Loretta J. Mickley, Matthew Cooper, and Francesca Dominici, Science Advances. https://www.science.org/doi/10.1126/sciadv.abi8789. Accessed August 13, 2021.

[27] California Independent System Operator, *Root Cause Analysis Mid-August 2020 Extreme Heat Wave,* p. 39. (Sacramento, CA: ISO), January 13, 2021, http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf#search=root%20cause. Accessed March 30, 2022.

[28] California Energy Commission. *Pacific Gas and Electric Company's Amended Post-PSPS Event Report For October 26 & 29, 2019*, p. 1. (Sacramento, CA: CEC), July 24, 2020, https://www.pge.com/pge_global/common/pdfs/safety/emergency-preparedness/natural-disaster/wildfires/PSPS-Report-Letter-10.26.19.pdf. Accessed March 7, 2024.

- **The loss of power during an adverse disaster can lead to adverse health outcomes within a building**. Without power, building heating, ventilation, and air conditioning (HVAC) systems are unable to provide temperature control, presenting a critical risk to the health and safety of building occupants, particularly vulnerable populations. A power outage following Hurricane Irma in 2017 left a nursing home without electricity to run air conditioning, allowing ambient temperatures in the building to rise to dangerous levels, contributing to the deaths of twelve residents. Subsequent analyses indicated of the 54,095 nursing home residents in Florida when Irma struck, more than half of residents experienced power loss after the hurricane, which was associated with an increased odds of mortality within days after the storm.[29]

- **Buildings designed for cooler climates may be most susceptible to extreme heat events.** The 1995 Chicago Heat Wave, lasting five days with frequent power outages, led to over 700 heat-related deaths.[30] Between 2015 and 2019, 5,700 excess deaths were observed during heatwaves in France. The summer of 2020 combined exceptionally high temperatures with the COVID-19 pandemic.[31] During extreme temperature events, buildings designed primarily for cooler environments without air conditioning become increasingly dangerous environments, increasing the risk of occupant heat stress.

According to the National Oceanic and Atmospheric Administration (NOAA), the number and cost of disasters are increasing over time, driven by greater exposure of more costly assets; growing vulnerability of buildings and infrastructure; and frequency of extreme weather events.[32] Climate change is increasing the frequency and intensity of some types of extreme weather. Increased precipitation, higher wind speeds, and drought patterns elevate the risk of flooding, hurricanes, and wildfire events, leading to more consequential disasters across all parts of the country.[33]

---

[29] David M. Dosa; Julianne Skarha; Lindsay J. Peterson; et al, “Association Between Exposure to Hurricane Irma and Mortality and Hospitalization in Florida Nursing Home Residents,” *JAMA Netw Open.* 2020;3(10):e2019460. https://jamanetwork.com/journals/jamanetworkopen/fullarticle/2771392, doi:10.1001/jamanetworkopen.2020.19460. Accessed March 30, 2022.

[30] U.S. Global Change Research Program, *Global Climate Change Impacts in the United States,* p.117. (New York, NY: Cambridge University Press), 2009, https://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf. Accessed March 30, 2022.

[31] Pascal M, Lagarrigue R, Laaidi K, Boulanger G, Denys S. Have health inequities, the COVID-19 pandemic and climate change led to the deadliest heatwave in France since 2003? Public Health. 2021 May; 194:143-145. doi: 10.1016/j.puhe.2021.02.012. Epub 2021 Apr 21. PMID: 33894555; PMCID: PMC8462812.

[32] Adam B. Smith, “2020 U.S. billion-dollar weather and climate disasters in historical context,” *Climate.gov*, January 8, 2021, https://www.climate.gov/news-features/blogs/beyond-data/2010-2019-landmark-decade-us-billion-dollar-weather-and-climate. Accessed November 14, 2023.

[33] USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1515 https://nca2018.globalchange.gov, doi: 10.7930/NCA4.2018.

Of relevance to building energy systems, the U.S. is experiencing increased exposure to extreme heat. Average temperatures are not only increasing, but so are temperature extremes. Experts project extreme heat days to increase in both intensity and duration.[34] As one of the more fatal natural hazards, elevated heat risks subject some populations, notably vulnerable and elderly groups, to adverse health impacts. Modeling these impacts in three U.S. cities, new research estimates that compound heat wave and grid failure events would expose more than two-thirds of urban residents to adverse health outcomes, including heat exhaustion stroke and heat stroke.[35] Energy codes that result in buildings that safely maintain the thermal environment are a critical requisite to the resilience of the built environment.

The impacts of and recovery efforts following extreme weather and disaster events expose the underlying vulnerabilities of a community. Lower-income households suffer disproportionately from the effects of a disaster. Living in older, lower quality homes offers less protection. These same disparities also exist by race, as non-white communities often face the adverse impacts of disasters.[36] Resiliency efforts must confront the structural and socioeconomic conditions that leave communities most susceptible to major disruptions. Building-level interventions can address the recurring burden perpetuated by disaster events perpetuate and improve resilience outcomes for the most vulnerable communities.

Strengthening the resilience of buildings equips communities, states, and the Nation at large to manage the complex risks and uncertainties disaster events impose. As government agencies and businesses grapple with how to make buildings and energy infrastructure more resilient, many are turning to energy codes as the policy mechanism of choice. While building codes currently accommodate a very broad range of functional needs and design considerations, including many aspects of resilient design, they can also evolve to address resilience more comprehensively in the built environment.

This report evaluates how building codes, specifically the role of building energy codes and energy efficiency strategies, can enhance resilience in residential and commercial buildings. The following sections provide additional background on the role of energy efficiency as a contributor to increased resilience, and an overview of supporting work being undertaken by DOE BTO, its programs and broader building design and construction industry (Section 2). Section 3 elaborates on the role of building codes and their application across Federal, state, and local resilience efforts. Shifting to the report's central findings, Section 4 discusses the

[34] K. Dahl, R. Licker, J. T. Abatzoglou, and J. Declet-Barreto, "Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century," *Environmental Research Communications* 1 (7), 075002 (2019). p. 10. https://doi.org/10.1088/2515-7620/ab27cf. Accessed March 8, 2024.

[35] Stone Jr, Brian, et al. "Compound Climate and Infrastructure Events: How Electrical Grid Failure Alters Heat Wave Risk." *Environmental Science & Technology* 55(10) (2021): 6957-6964. (Preprint.) p. G. DOI: 10.1021/acs.est.1c00024. Accessed March 1, 2023.

[36] U.S. Environmental Protection Agency. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. p. 6 EPA 430-R-21-003. www.epa.gov/cira/social-vulnerability-report. Accessed November 14, 2023.

intersection of energy efficiency strategies, building codes, and resilience, providing evidence as to how energy efficient technologies can enhance building energy resilience. Section 5 identifies research needs, opportunities, and recommendations for further study, and is followed by a summary of current BTO efforts to addresses these needs (Section 6).

II. Background

The mission of the DOE BTO is to advance energy-efficient technologies across the residential and commercial building sector. Several ongoing projects aim to improve the resilience of communities, create jobs, and build a stronger economy. To support goals across the Office of Energy Efficiency Renewable Energy (EERE), BTO's work explores the integration of high-performance, energy-efficient buildings alongside energy infrastructure systems to deliver affordable, reliable, and less intensive energy services.[37] This commonly includes research, development, and deployment of advanced energy efficiency technologies and practices, as well as their integration with a variety of building types, distributed energy resources, and their interconnectedness with the utility grid. BTO also emphasizes the role of energy efficiency and resilience, particularly in its R&D programs and work on buildings-grid integration.[38]

Building Energy Codes Program

In the United States, nearly 6 million commercial buildings and 123.5 million residential households consume about 37% of the total energy consumption and 70% of total electricity consumption.[39,40,41] Because buildings typically exist for decades, and in many cases even centuries, energy codes represent a unique opportunity to ensure buildings are designed and constructed to minimum acceptable levels of energy performance, which has lasting impacts on energy consumption. Addressing energy efficiency during new construction and major renovations can also be far more cost-effective than doing so during costly later upgrades, which can result in significant disruption to the building's occupants and operations. Establishing and improving energy code requirements over time helps typical design and construction practices remain on par with current and cost-effective technologies, and ensures more efficient, healthier, and affordable living and working environments for future generations.

The Building Energy Codes Program (BECP) is a technical assistance program. Its mission is to support building energy code development and implementation processes to achieve

[37] U.S. Department of Energy, Building Technologies Office. *Building Technologies Office Multi-Year Program Plan: Fiscal Years 2016 – 2020*. February 2016. https://www.energy.gov/sites/prod/files/2016/02/f29/BTO%20Multi-Year%20Program%20Plan%20-%20Final.pdf. Accessed March 8, 2023.
[38] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Grid-Interactive Efficient Buildings," https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings. Accessed March 8, 2023.
[39] U.S. Energy Information Administration. *2018 Commercial Building Energy Consumption Survey*. Table B1. https://www.eia.gov/consumption/commercial/data/2018/#b1-b2. Accessed March 8, 2023.
[40] U.S. Energy Information Administration. *January 2024 Monthly Energy Review*. Tables 1.1 and 2.1a. https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf. . Accessed March 7, 2024.
[41] *Ibid.* Table 7.6. (2022 estimates.). Accessed March 7, 2024.

practicable, cost-effective improvements in energy efficiency while providing safe, healthy buildings for occupants. BECP fulfills statutory directives by participating in industry processes to develop model building energy codes, including the International Energy Conservation Code (IECC) and American National Standards Institute (ANSI)/American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)/IES Standard 90.1,[42] and issuing *determinations* as to whether updated codes result in increased building energy efficiency.[43] In addition, BECP provides technical assistance for state code implementation, supporting states and municipalities as they adopt, update, and improve compliance with energy codes.

BECP works closely with code development bodies, the broader building design and construction industry, including builders, architects, engineers, and the trades, state, and local governments, and the public. BECP produces technical analyses that quantify energy savings, cost-benefit, and other impacts, conducts research to validate code impacts, and maintains tools that streamline code compliance processes. The codes program also tracks and analyzes state energy codes as shown in Figure 2 and Figure 3 below.

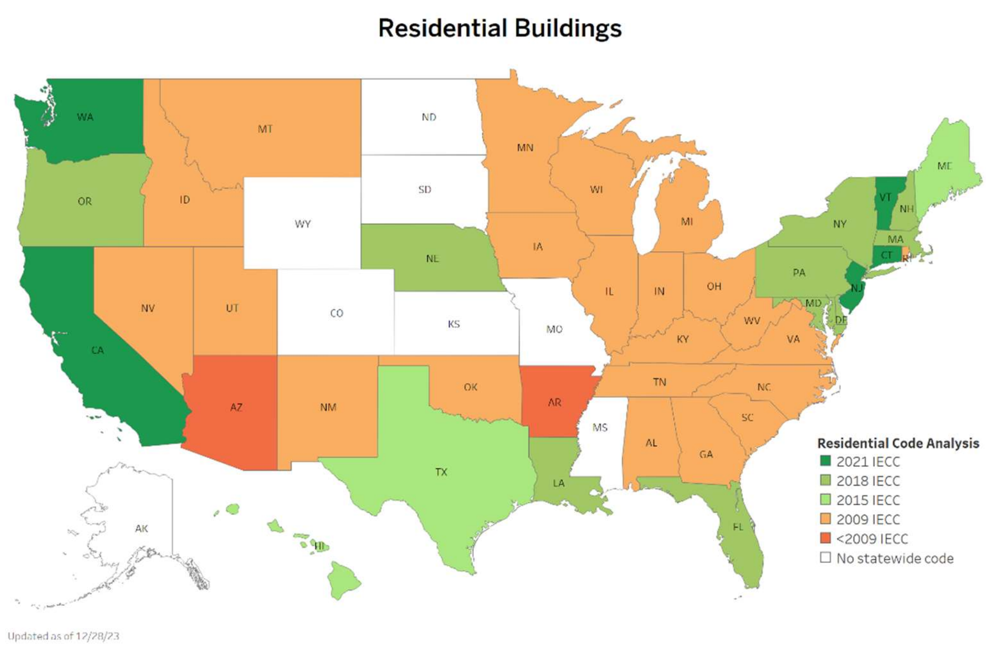

Figure 2: Status of state energy code adoption for residential buildings.[44]

---

[42] The model energy codes, the IECC and Standard 90.1, are administered by the ICC and ASHRAE, respectively, through public development and consensus proceedings, in which any interested party can participate.
[43] U.S. Department of Energy Building Energy Codes Program, "Determinations," https://www.energycodes.gov/determinations. Accessed March 8, 2023.
[44] U.S. Department of Energy Building Energy Codes Program, "Status of State Energy Code Adoption," https://www.energycodes.gov/state-portal. Accessed March 8, 2024.

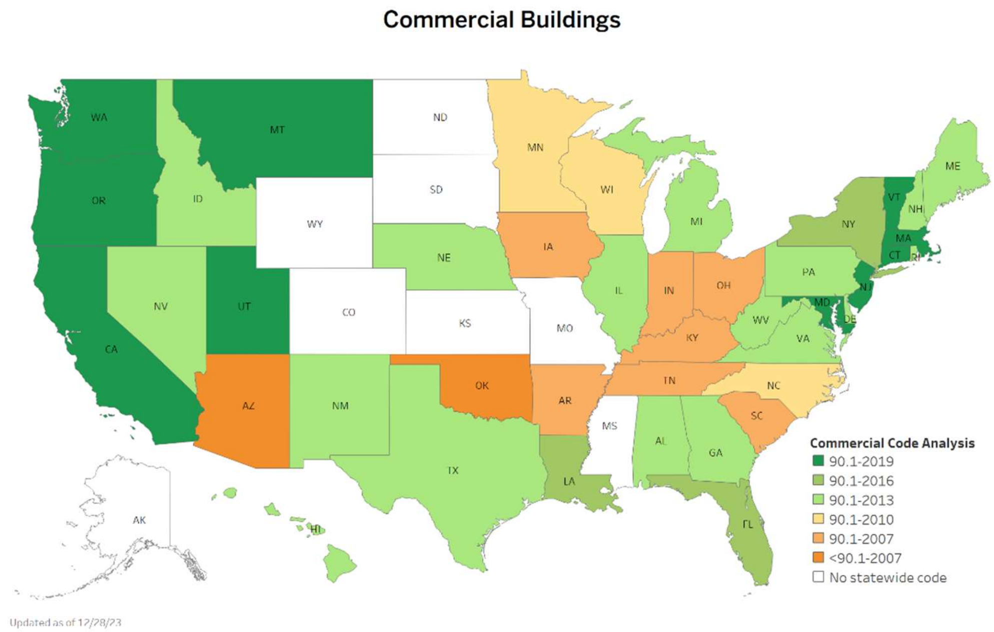

Figure 3: Status of state energy code adoption for commercial buildings.[45]

Energy codes for residential and commercial buildings are estimated to save a cumulative 16.1 quadrillion BTU of primary energy, equivalent to over $182 billion in energy savings.[46] Energy efficiency benefits, such as those provided by building codes and standards, play a significant role in reducing power demand, bolstering reliability of the grid, and enhancing overall system resilience. Figure 4 shows how model energy codes, the IECC and Standard 90.1, have incrementally reduced building energy use in residential and commercial buildings, respectively, through recent iterations of the three-year industry code development cycle.

[45] Ibid.

[46] Department of Energy Building Energy Codes Program, "The Impact of Building Energy Codes," https://www.energycodes.gov/impact-analysis. Accessed March 8, 2023.

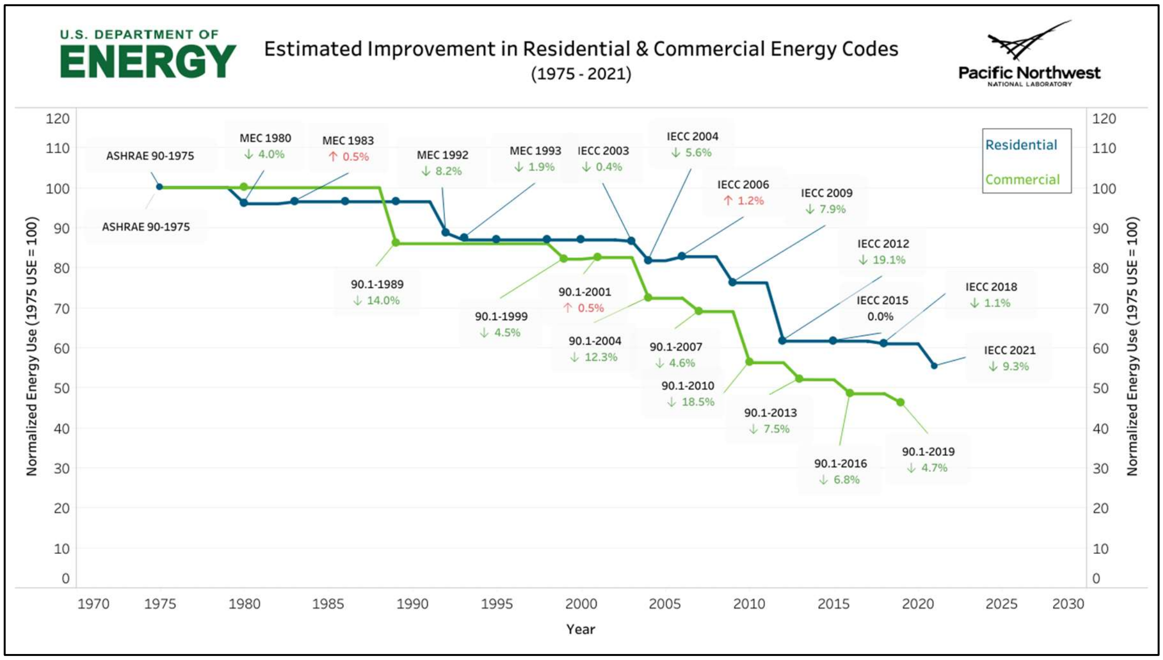

Figure 4: Model energy code efficiency achievements. Source: PNNL (2023).[47]

Workshop on the Nexus of Energy Efficiency and Resilience

To investigate the relationship between resilience and energy efficiency, BTO in partnership with Oak Ridge National Laboratory (ORNL) convened a workshop on June 12–13, 2019. The workshop included a diverse group of industry experts and stakeholders, representing Federal, state, and local governments, researcher institutions, non-profits, building design and construction firms, building technology manufacturers, and community development organizations. The workshop focused on behind-the-meter building technologies, with an emphasis on identifying how efficiency and load flexibility measures complement, conflict with, or have no impact on building resilience. Participants discussed how building resilience impacts a variety of different stakeholders including occupants, owners, businesses, utilities, and communities.

The workshop provided valuable insight on potential research gaps, technology development, and program opportunities for BTO.[48] Notable takeaways from the workshop include:

- Resilience valuation was identified as both a critical challenge and opportunity. The lack of a standardized methodology to value resilience was seen as a primary current challenge but also as an opportunity.
- Building codes and standards were identified as specific opportunities to simultaneously address energy efficiency and resilience goals.

[47] Generated from internal PNNL analysis. 2023.

[48] Ronald D. Ott, Scott Morgan, and Matthew Antes, *Workshop on the Nexus of Resilience and Energy Efficiency in Buildings: Proceedings Report*, Oak Ridge National Laboratory (ORNL), No. ORNL/TM-2019/1352 (Oak Ridge, TN), September 30, 2019. https://doi.org/10.2172/1606900.

- High-priority actions reflected the need to establish benchmarks and financing incentives to garner support within the broader industry, including participation from the insurance sector.
- An energy-resilience matrix was developed; it identified energy efficient technologies and outlined whether they were anticipated to complement, conflict, or have no correlation to resilience risks (summarized in Table 2 below).

Table 2: Preliminary Matrix of Energy Efficiency Measures Relationships to Resilience Risk

Hazard Risk	Energy Efficiency Measures	
	Can Complement	Can Conflict
Wildfires	Unvented attics/crawl space Noncombustible material Balanced ventilation	Vented attics/crawl space High R-value insulation Natural ventilation
High Winds/Impact (hurricanes, tornadoes)	Unvented attics Masonry walls Operable shutters	Vented attics Multi-paned windows Natural comfort overhangs
Earthquakes	Wood framed walls	Masonry walls
Floods	Masonry walls Sprayed foam insulation	Unvented crawl space Insulated foundation slab
Severe Winter Weather	Vented attics Increased insulation Ducts in conditioned space Heat pump water heaters	Unvented attics Insulation air gaps
Post-Event Occupancy	High-performance enclosure Natural ventilation Solar Electric/thermal Battery + PV backup	Non-operable windows Masonry walls

For example:

- Vented attics are considered a poor design choice in wildfire zones because they increase the risk of embers entering a building. But in harsh winter conditions, vented attics prevent ice dams and moisture buildup from melted snow.
- Higher R-value insulation is associated with maintaining livable indoor temperatures for longer durations during an extreme heat or cold event, making it a complementary resilience technology and enabling sheltering-in-place during post-event occupancy scenarios. However, certain insulation materials were also identified as flammable and could be hazards in wildfire prone regions.
- Natural ventilation can help maintain livable indoor air temperatures during a power outage (i.e., when mechanical ventilation systems are not operations), but can pose a risk in areas prone to wildfire due to smoke intrusion.

Overall, the workshop highlighted the untapped potential to design buildings for both optimal energy performance and resilience. The above examples also suggest that design strategies are not universal, but dependent on the local hazards and climate of a region.

What is Building Energy Resilience?

The concept of resilience is a framework broadly used across disciplines to characterize a system's response to disruptive events. Resilience has become a fixture of public policy and programs across Federal, state, and local levels. The rising costs and impacts of disasters have exposed the need for more resilient infrastructure and buildings.[49] In line with prior reports and initiatives at the Federal level, resilience is defined as:

The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.[50]

Adverse events include natural disasters (e.g., hurricanes, wildfires, flooding, tornadoes, earthquakes), as well as other threats (e.g., cyberattacks, pandemics, terrorism). Disasters often trigger secondary and cascading disruptions that further compromise the operational capacity of buildings. For example, hurricane force winds can knock out energy infrastructure, leading to prolonged power outages.

A growing body of work is dedicated to the resilience of communities, buildings, and energy infrastructure, respectively. Resilient buildings are often defined based on their structural vulnerability to natural hazards. Ongoing work, notably by the National Institute of Building Sciences (NIBS), has also extended the value of building resilience to consider secondary impacts to business interruption, fatalities, displacement costs, and loss of community services.[51]

The resilience of buildings and energy systems are interdependent. That building design strategies can benefit both energy efficiency and resilience is the subject of a growing discourse. However, the lack of concise definitions, methods to measure progress, and actionable guidance has made the concept of resilience difficult to operationalize.[52] Embedding energy efficiency and resilience within a single definition, for the purposes of this report building energy resilience is defined as:

---

[49] U.S. Department of Homeland Security, *Designing for a Resilient America: A Stakeholder Summit on High Performance Resilient Buildings and Related Infrastructure. US DHS Department of Homeland Security*, 2010, https://www.dhs.gov/xlibrary/assets/st-designing-for-resilient-america.pdf. Accessed November 14, 2023.

[50] National Research Council. Disaster Resilience: A National Imperative. 2012. p. 16. Washington, DC: The National Academies Press. https://nap.nationalacademies.org/catalog/13457/disaster-resilience-a-national-imperative. Accessed March 8, 2024..

[51] Multi-Hazard Mitigation Council, *Natural Hazard Mitigation Saves: 2019 Report* (Washington DC: NIBS), 2019. https://www.nibs.org/projects/natural-hazard-mitigation-saves-2019-report. Accessed March 15, 2023.

[52] Davidson, Julie L., et al. "Interrogating resilience: toward a typology to improve its operationalization." *Ecology and Society* 21.2:27 (2016). http://dx.doi.org/10.5751/ES-08450-210227 Accessed March 15, 2022.

The capacity of building energy services—heating, cooling, ventilation, lighting, cooking, refrigeration, electric plug loads, and enclosures—to support buildings and energy infrastructure systems preparation and planning for, absorption of, recovering from, and more successfully adapting to adverse events. (Working definition of energy resilience utilized by DOE BTO.)

The definition above could provide an operational framework to characterize building energy resilience that can be applied through building energy codes. Buildings that are both energy efficient and resilient are better equipped to absorb the shocks of disruptive events, thereby strengthening the resilience of the community at large.

Figure 5 depicts the concept of resilience. The figure shows the response and recovery of two theoretical systems during a disruptive event. In the context of buildings, system performance represents building energy services (i.e., heating, cooling, refrigeration, lighting, and ventilation). Building design measures, such as insulation, efficient windows, and air sealing, increase building energy performance. These measures allow building occupants to shelter in place, provide increased structural support, and reduce exposure to any secondary hazards during and following a disruptive event. Buildings are better equipped to absorb the shocks and stresses of a disaster event as normal operations are restored.

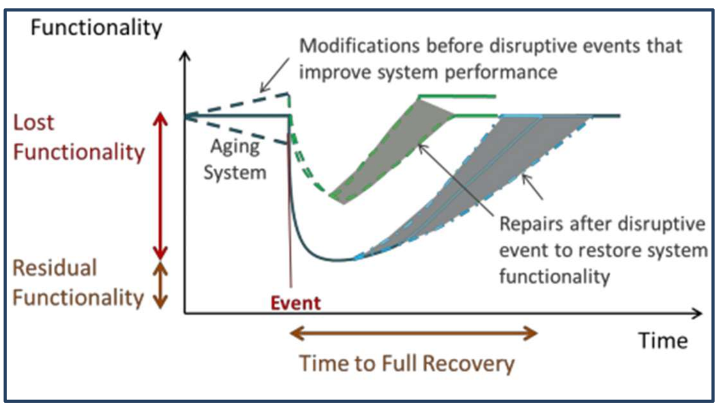

Figure 5: Dynamic response to a disruption. Reprinted from NIST (2013).[53] Original McDaniels (2008).[54]

Drawing from existing literature on resilience within the built environment, the NIST paper characterizes energy resilience across the three stages of a disaster event: preparedness, response, and recovery.

[53] McAllister, T. (2013), Developing Guidelines and Standards for Disaster Resilience of the Built Environment: A Research Needs Assessment (NIST TN 1795), Technical Note (NIST TN), National Institute of Standards and Technology, Gaithersburg, MD. p. 18. https://doi.org/10.6028/NIST.TN.1795. Accessed March 15, 2023.
[54] McDaniels, Timothy, et al. "Fostering resilience to extreme events within infrastructure systems: Characterizing decision contexts for mitigation and adaptation." *Global Environmental Change* 18.2 (2008): 310-318.

Disaster Preparedness

Disaster preparedness refers to building design features—both structural and nonstructural components—that mitigate the potential impacts of a hazardous event. The building structure is comprised of its foundation, walls, windows, roof, and supporting connections. These features support the building's *structural resilience, or* ability to rapidly resume the use of buildings and structures following a shock incident or event.[55] Structural resilience is based on the building's ability to physically withstand the impacts of natural disasters, as opposed to energy resilience, which is centered around passive survivability and energy system reliability. Building structures are designed to tolerate local hazards, such as snow loads, wind loads from hurricanes or tornadoes, seismic loads during earthquakes, and flood events. The structural integrity of a building typically reflects the minimum standards dictated by building codes.

Building energy efficiency reflects interactions between equipment, operations, and energy load to perform a specific function. Energy loads are mediated through passive design measures, such as the building envelope. By reducing load sizes, energy efficiency improves building performance and increases occupant comfort while reducing impacts on the built environment.

As part of interactions between building services and the power grid, energy efficiency can contribute to the resilience of the electric grid. Grid resilience describes the reliability, delivery, and recovery of electricity supply in the face of adverse weather events.[56] As part of a coupled system, a resilient electric grid increases the energy resilience of buildings during major disruptions.

Disaster Response

Disaster response can be characterized by operational resilience and passive survivability.

Operational resilience refers to the performance of a building during a disaster event, through which critical infrastructure services (e.g., disaster shelters, hospitals, water treatment, emergency management) are provided.[57] The operational capacity of a building is a function of the availability of an energy supply, whether from a fuel source, the energy grid, or a backup system. Additional design requirements, scheduled maintenance, and planning ensure buildings can maintain operational capacity throughout a major disruption.

These considerations allow buildings to island, i.e., disconnect from the power grid and rely on backup power systems. DOE R&D is investigating the ability of PV solar systems, battery

---

[55] https://www.istructe.org/resources/resilience/. Accessed May 31, 2023.

[56] Executive Office of the President, *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages* (Washington, DC), August 2013, https://www.energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf. Accessed November 14, 2023.

[57] A. Ganin, E. Massaro, A. Gutfraind, et al., "Operational resilience: concepts, design and analysis," *Scientific Reports* 6, 19540 (2016), https://www.nature.com/articles/srep19540 .

storage, and enhanced efficiency measures to maintain building operations.[58] Energy efficiency dictates the performance of building energy systems (i.e., by way of building energy codes), and increasingly the ability to load-switch and operate in a reduced capacity or during a complete outage (i.e., when combined with backup power).

When energy delivery is interrupted, buildings must rely on their intrinsic designs. *Passive survivability* describes the ability of a building to maintain safe thermal conditions without energy. Passive survivability enables building occupants to *shelter-in place* during and following a disaster event.[59] The thermal performance of the building sustains indoor air temperatures within safe limits. The duration and degree to which indoor temperatures are sustained within a given threshold are two key factors used to measure passive survivability.

The application of passive survivability is most relevant during extreme heat and cold temperature events. Seventy-two hours is a common duration used as a reference case to track indoor thermal conditions over the course of a given outage event within literature and design criteria guidance. Thermal impacts are less detectable for shorter duration events, whereas buildings are likely to reach equilibrium with ambient temperatures for durations more than a week.

As a dynamic measurement of thermal conditions over time, passive survivability can be represented using different metrics. Summarized below are commonly used metrics:

- Heat index, wet-bulb temperature, and standard effective temperature are three metrics that combine both temperature and humidity.
- Degree-hours is an integrated metric that captures both the magnitude (in degrees) and duration (in hours) over the course of a given event.

Hours of safety is a time-based metric that measures the hours a building can maintain safe temperatures within a given threshold. This metric is also useful from the design and modeling perspective to compare the hours of safety different building designs can achieve under a given outage and/or extreme temperature event.[60]

Recovery and Restoration Following Disruption

Recovery and restoration efforts following a disruption are driven by pre-disaster mitigation strategies. Resilient buildings are more able to return to normal operation and avoid extensive

[58] DOE Better Buildings, *How Distributed Energy Resources Can Improve Resilience in Public Buildings: Three Case Studies and a Step-by-Step Guide*, September 2019. https://www.energy.gov/sites/prod/files/2019/09/f66/distributed-energy-resilience-public-buildings.pdf. Accessed November 14, 2023.

[59] International Code Council, *The Important Role of Energy Codes in Achieving Resilience*, n.d., https://www.iccsafe.org/wp-content/uploads/19-18078_GR_ANCR_IECC_Resilience_White_Paper_BRO_Final_midres.pdf. Accessed November 14, 2023.

[60] Sneha Ayyagari, Michael Gartman, and Jacob Corvidae, "Hours of Safety in Cold Weather: A Framework for Considering Resilience in Building Envelope Design and Construction." Rocky Mountain Institute. p. 2.2020. https://rmi.org/insight/hours-of-safety-in-cold-weather/. Accessed March 15, 2023.

impacts from a disaster. The recovery process is a concerted effort across an impacted community made possible by the availability of building energy supply. Critical lifelines, specifically food, water, sanitation, and shelter are essential buildings energy services necessary to initiate any recovery process.

Research on earthquake resilience refers to this phase as *functional recovery*, or the restoration of building services needed to support normal building operations.[61] Functional recovery considers building designs that support both safety and recovery time. The concept of functional recovery lends itself to energy resilience, where critical building energy loads can be prioritized to enable recovery processes and reduce any secondary impacts from the acute disruption. The restoration of the grid to power building energy services is a primary determinant of the duration of the recovery. Additionally, flexible building energy loads can aid the strategic restart of a grid.

Buildings and Power Disruptions

The U.S. power system continues to evolve, reshaping how energy is produced, delivered, and consumed. On the supply side, the steady growth of renewable energy generation offers a variable, carbon-free power source. Climate and clean-energy goals to decarbonize the energy system will require greater reliance on renewable power sources. End-use energy demand is expected to increase electricity consumption as buildings shift away from fossil-based fuels. As a result, building-grid connectivity will serve a more prominent role in managing electricity delivery. The deployment of distributed energy resources (DERs), such as rooftop solar, energy storage, and grid-enabled building technologies have embedded building energy systems as a dynamic resource within the power system.[62]

Despite these advances, many aspects of the energy grid remain outdated, and the lack of major upgrades has left energy infrastructure more suspectable to disruptions. The American Society of Civil Engineer's annual report estimates the electricity infrastructure investment gap to be more than $200 billion by 2029.[63] The resilience of the electric grid against a growing number of disaster events is the topic of significant ongoing effort at the Federal level. A 2013 DOE report estimates that power outages cost the United States $28 to $169 billion annually.[64]

---

[61] Federal Emergency Management Agency, National Institute of Technology, *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time*, January 2021. FEMA P-2090/ NIST SP-1254. https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1254.pdf. Accessed November 14, 2023.

[62] DOE EERE, "Grid-interactive Efficient Buildings," DOE/EE-1922, April 2019, Ahttps://www.energy.gov/sites/prod/files/2019/04/f62/bto-geb-factsheet-41119.pdf. Accessed November 14, 2023.

[63] American Society of Civil Engineers, Failure to Act: Electric Infrastructure Investment Gaps in a Rapidly Changing Environment (Reston, VA: 2020).

[64] President's Council of Economic Advisers and the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability, "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages," Aug. 2013, https://www.energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf. Accessed November 14, 2023.

Researchers anticipate an increase in extreme weather events will further strain key grid components and cause more widespread outages that will have longer recovery times.[65]

Since 2000, there has been a 67% increase in major power outages from weather-related events. (Source: Climate Central[66])

Weather and temperature are two critical factors that drive building energy system management and utility projections.[67] Temperature swings are the primary driver of peak energy demand. In the United States, cooling energy represents almost 30% of the peak load yet is responsible for only 15% of annual electricity consumption.[68] The ability of grid operators and utilities to meet peak demand tests the performance and operational capacity of the electric grid. When grid infrastructure is overloaded, power outages can occur at both the local and regional level.

The availability of power is fundamental to the continuity of building operations during all types of disruptions. The predicted increase in such events highlights the need for energy efficiency strategies that, implemented in concert, enhance the resilience of the built environment, no matter what type of disaster occurs. Disaster resilience at the building-level is essential, but for its effectiveness to be fully realized, it must account for the broader energy system and the complex interdependences between buildings, the grid, critical services, and energy supply.

Advancing Equity through Building Energy Resilience

The Texas winter storm event created freezing conditions that posed the greatest threat to low-income communities of color. In Texas, these communities tend to live in older, poorly insulated homes that exacerbate preexisting hardships, lacking the necessary stopgaps protections to withstand such an event. Research following the event has revealed that these same communities endured greater impacts, as they endure more widespread blackouts. [69] Based on analysis that used satellite imagery to track changes in illumination, researchers found that areas of high minority and low-income populations were more than four times as likely to

[65] Larsen, Peter H., et al. "Projecting future costs to US electric utility customers from power interruptions." *Energy* 147 (2018): 1256-1277. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6855308/. Accessed November 14, 2023.

[66] Climate Central, "Power OFF: Extreme Weather and Power Outages," September 30, 2020, https://www.climatecentral.org/climate-matters/power-outages. Accessed November 14, 2023.

[67] U.S. Global Change Research Program, "Temperature Changes in the United States," Chapter 6 in *Climate Science Special Report, Fourth National Climate Assessment, Volume I*, D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock (eds.), (Washington, DC), 2017. https://science2017.globalchange.gov/chapter/6/. Accessed March 8, 2024.

[68] International Energy Agency and Organisation for Economic Co-operation and Development, *The Future of Cooling: Opportunities for energy-efficient air conditioning*, 2018, https://www.oecd.org/about/publishing/TheFutureofCooling2018Corrigendumpages.pdf. Accessed November 14, 2023.

[69] Ali Nejat, Laura Solitare, Edward Pettitt, Hamed Mohsenian-Rad. "Equitable Community Resilience: The Case of Winter Storm Uri in Texas." https://arxiv.org/ftp/arxiv/papers/2201/2201.06652.pdf. Accessed April 11, 2022.

suffer a blackout compared to predominantly white areas.[70] The research depicts a sobering portrayal of inequality across communities and energy infrastructure. Investments to enhance resilience—of energy infrastructure, critical services, and buildings—often leaves the most vulnerable communities behind. Efforts to address the resilience of buildings and energy infrastructure must prioritize the needs of historically underserved communities.

Disasters expose underlying vulnerabilities within a community, of both its physical infrastructure and social capacities. A growing body of research documents the adverse impacts underserved communities face from extreme weather events. Disasters exacerbate existing housing deficiencies conditions and cause longer-term health and safety hazards. Chronic respiratory ailments and other adverse health outcomes have been linked to individuals exposed to hazards such as debris, toxic chemicals, and mold and microbial products.[71]

Disadvantaged communities are less able to afford insurance policies and rebuilding costs, and thus face greater obstacles to recovery. Disasters not only impose greater damage to vulnerable communities, but in fact increase existing disparities in the areas of race, income, homeownership, and education.[72] Calls for resilience must account for the social and economic inequalities that render disadvantaged communities more vulnerable to extreme weather events.[73]

Federal efforts are underway to ensure programs advance equity and increase resilience for communities—especially communities that are disproportionately at risk of climate change impacts.[74] Through the Justice40 Initiative, DOE leads efforts to establish a framework to ensure 40% of the benefits of climate investments go to disadvantaged communities.[75] In

---

[70] Feng Chi Hsu, Jay Taneja, JP Carvallo, Zeal Shah. "Frozen out in Texas: Blackouts and Inequality." Funded by the Rockefeller Foundation. April 14, 2021. https://www.rockefellerfoundation.org/case-study/frozen-out-in-texas-blackouts-and-inequity/. Accessed November 14, 2023.

[71] Committee on Post-Disaster Recovery of a Community's Public Health, Medical, and Social Services; Board on Health Sciences Policy; Institute of Medicine, "Healthy Housing," from *Healthy, Resilient, and Sustainable Communities After Disasters: Strategies, Opportunities, and Planning for Recovery* (Washington, DC: National Academies Press), September 10, 2015. https://nap.nationalacademies.org/catalog/18996/healthy-resilient-and-sustainable-communities-after-disasters-strategies-opportunities-and. Accessed March 8, 2024.

[72] Howell, Junia, and James R. Elliott. "Damages done: The longitudinal impacts of natural hazards on wealth inequality in the United States." *Social Problems* 66.3 (2019): 448-467.

[73] Baker, Shalanda Helen, Anti-Resilience: A Roadmap for Transformational Justice within the Energy System (2019). Harvard Civil Rights- Civil Liberties Law Review (CR-CL), Vol. 54, pp. 1-48 (2019), Northeastern University School of Law Research Paper No. 346-2019, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3362355. Accessed November 14, 2023.

[74] The United States Government. (2021, May 24). *FACT SHEET: Biden Administration Invests $1 Billion To Protect Communities, Families, and Businesses Before Disaster Strikes*. The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/24/fact-sheet-biden-administration-invests-1-billion-to-protect-communities-families-and-businesses-before-disaster-strikes/. Accessed November 14, 2023.

[75] U.S. Department of Energy, "Promoting Energy Justice," https://www.energy.gov/promoting-energy-justice. Accessed November 14, 2023.

addition, in its latest report, the Federal Emergency Management Agency's (FEMA) advisory council acknowledged that their programs restrict equitable outcomes, as they fail to serve less-affluent communities each disaster cycle.[76]

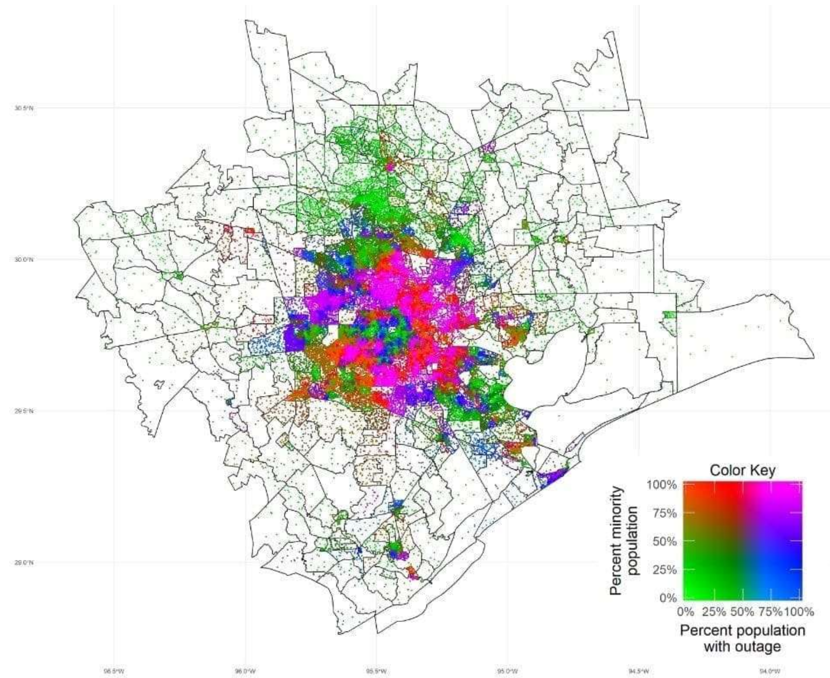

Figure 6: Map of Houston, Texas and surrounding area showing percent of population that experienced outage over percent minority population during a February winter storm. One dot represents 100 people. Source: Rockefeller Foundation (2021).[77]

Targeting energy resilience investments at the building level can help ensure that disadvantaged communities experience direct benefits. Buildings that are both efficient and resilient increase energy affordability, mitigate health risks, and improve thermal comfort, while also reducing the potential impacts of adverse weather events. Enhanced energy resilience at the community level can reduce the risk of outages, property damage, and disruption of community services. These benefits address the vulnerabilities embedded in underserved communities and provide a pathway to strengthen their socioeconomic well-being.

The development and adoption of building energy codes provides a formal process to preserve the benefits of energy resilience in practice. Building codes establish a baseline that can support the overall resilience of communities. In turn, communities are more prepared to face the growing threats posed by climate change.

[76] National Advisory Council. "Report to the FEMA Administrator," November 2020, https://www.fema.gov/sites/default/files/documents/fema_nac-report_11-2020.pdf. Accessed November 14, 2023.

[77] Feng Hsu, Jay Taneja, JP Carvallo, Zeal Shah. Op. cit.

III. Enhancing Resilience Through Building Codes

Building codes set minimum standards that inform the construction of safe, sustainable, affordable, and resilient structures against natural hazards. As a means of supporting community resilience, building codes:

- are developed in coordination across design sections— including energy, plumbing, mechanical, electrical, and fire codes;
- evolve over time in response to industry priorities, practices, and needs of the built environment, including intensifying or shifting hazard risks; and
- energy codes, a subset of building codes, set energy efficiency standards in residential and commercial buildings, and represent an opportunity to increase the energy resilience of these buildings.

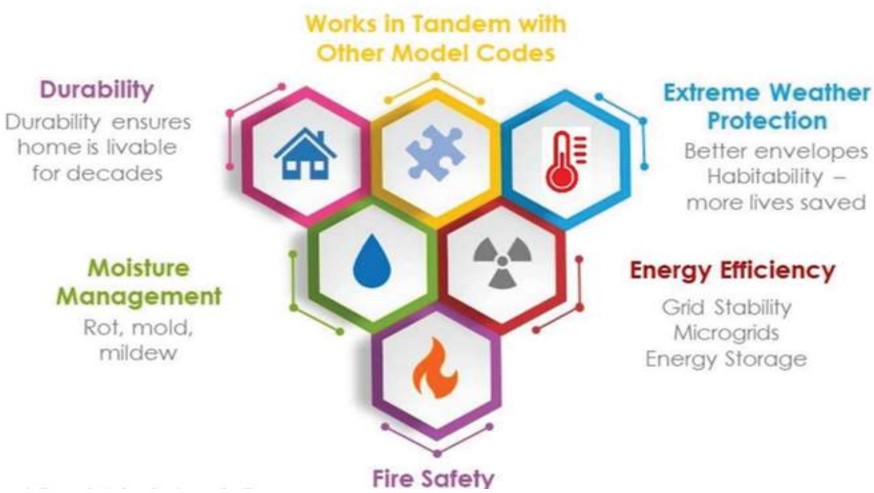

Figure 7: Coordination of code provisions to mitigate potential threats (Source: ICC/ANCR).

The following sections provide background on the code development and implementation framework and how it can be leveraged to enhance energy resilience in buildings.

Role of the Code Development Process

Building codes are developed through the International Code Council (ICC), which leads the code development and update process for commercial and residential buildings. Through an industry consensus process, the ICC updates its code every 3 years to incorporate evolving building technologies and construction practices.[78] Industry stakeholders include: the building design and construction industry (e.g., architects, engineers, builders, building officials the trades, among others), Federal, state, and municipal government agencies, and the public. The ICC family of building codes, known as the "I-Codes," and inclusive of energy codes like the

[78] International Code Council, "The International Codes," https://www.iccsafe.org/products-and-services/i-codes/the-i-codes/. Accessed November 14, 2023.

IECC[79] (and ANSI/ASHRAE/IES Standard 90.1 by reference[80]) are developed, revised, and updated via this process, and enacted in some form in every state.

While building codes have long addressed natural hazards—for example, structural requirements to support expected wind and snow loads—the code development process has become a focal point for the movement to increase resilience in the built environment. Technologies that support building resilience, such as onsite photovoltaic (PV) systems combined with battery storage, might be addressed in several different codes, in provisions focused structural elements, to electrical systems, energy systems, and fire prevention.

The building industry is looking to the code development process to address resilience challenges, as contemporary building codes are recognized as a prerequisite to any resilience initiative. Disaster response efforts that incorporate mitigation-based programming, including the application of building energy resilience measures detailed in codes, can address community needs.

Other Government Agency Code Programs

Federal agencies have begun to encourage that building codes play an active role in community-wide resilience planning through incentives or funding requirements. DOE has multiple funding programs to support updated and resilient energy codes, and other agencies, such as the Federal Energy Management Agency (FEMA), the Department of Housing and Urban Development (HUD), and the Department of Homeland Security (DHS), have incorporated building codes into their programming. There are also many other Federal initiatives, particularly under the BIL and IRA, which are also complementary to building energy codes and increased resilience. This section highlights relevant work being undertaken across other government agencies to lead and influence building resilience efforts.

Through the passage of the Bipartisan Infrastructure Law (BIL) in 2021 and the Inflation Reduction Act (IRA) in 2022, DOE was allocated over $1.2 billion to support the adoption and implementation of updated energy codes for energy efficiency and resilience. The first program, $225 million through BIL, supports code implementation activities in states, jurisdictions, and tribal territories updating their energy codes. The first round of BIL funding awards, named the Resilient and Efficient Codes Implementation (RECI) funding opportunity,

---

[79] The International Code Council (ICC) maintains and delivers a comprehensive set of building codes, including the IECC, which establishes minimum requirements for the design and construction of building systems, such as structural, plumbing, electrical, and energy systems. The IECC is a dedicated section within the parental building codes, the IBC, and IRC and sets minimum requirements for energy efficiency in new and renovated residential and commercial buildings. The current edition is the 2024 IECC (which references ANSI/ASHRAE/IES 90.1-2022 as a compliance option in commercial buildings).

[80] ANSI/ASHRAE/IES Standard 90.1 is referenced by the commercial provisions of the IECC. Standard 90.1 provides the minimum requirements for energy-efficient design of commercial building (excluding low-rise residential buildings). The current edition is Standard 90.1-2022.

was announced in July of 2023, with several projects focusing on resilience.[81] The second program, $1 billion IRA-funded Technical Assistance for Building Energy Codes, supports updates to the "latest model energy codes" (i.e., ASHRAE 90.1-2019 and 2021 IECC)[82] and "zero energy codes" for states, territories, and units of local government with the authority to adopt building codes.[83] Both programs incentivize the adoption and implementation of updated energy codes, as well as broader resilience planning, and are expected to positively impact the resilience of buildings.

DOE also administers many other programs which support increased resilience, and which are complementary to the above funding initiatives supporting building energy codes. In particular, the Weatherization Assistance Program (WAP), State Energy Program (SEP), and Energy Efficiency Block Grants (EECBG) help fortify homes and buildings against hazards, and can provide support for building energy codes, in addition to a range of other activities, such as DOE's contractor training grants. DOE's Building Energy Codes Program helps advance model energy codes toward increased cost-effective energy efficiency and resilience, including supporting updated editions of the IECC and Standard 90.1, in addition to providing ongoing technical assistance to states and communities who ultimately adopt and implement energy codes, including technical assessments of updated codes, workforce development and education, and a range of compliance-support activities. DOE also actively supports other Federal agencies who hold statutory responsibilities surrounding building codes, including participation in the Federal Building Code Task Force and contributions to the National Initiative to Advance Buildings Codes (NIABC), as well as supporting the recent HUD/USDA determination which is based on recent editions of the IECC and Standard 90.1 and establishes the minimum energy standard for many federally-funded housing programs.

In 1988, the Stafford Disaster Relief and Emergency Assistance Act[84] created a system by which a presidential emergency declaration initiates and coordinates financial and physical relief programs through FEMA. In 2018, the Act was amended by the Disaster Recovery and Reform Act (DRRA). The amended policy marked a fundamental shift in priorities from traditionally reactive—and very costly—disaster response framework to a more proactive approach centered on mitigation.[85] DRRA provides additional incentives or jurisdictions to adopt, enforce, and implement the latest building codes through pre-disaster mitigation grants and post-

[81] DOE EERE Building Energy Codes Program, *Resilient and Efficient Codes Implementation*, https://www.energycodes.gov/RECI. Accessed March 29, 2024.
[82] ASHRAE Standard 90.1-2019 and the 2021 IECC are specified in IRA Section 50131 and were the latest model energy codes upon passage of the IRA.
[83] DOE State and Community Energy Programs, *Technical Assistance for the Adoption of Building Energy Codes*, https://www.energy.gov/scep/technical-assistance-adoption-building-energy-codes. Accessed March 29, 2024.
[84] FEMA, *Robert T. Stafford Disaster Relief and Emergency Assistance Act*, PL 100-707, signed into law November 23, 1988, amended the *Disaster Relief Act of 1974*, PL 93-288, https://www.fema.gov/disaster/stafford-act. Accessed November 14, 2024.
[85] FEMA, *Disaster Recovery Reform Act of 2018*, October 5, 2018, https://www.fema.gov/disaster/disaster-recovery-reform-act-2018. Accessed November 14, 2023.

disaster rebuilding efforts, and is one of the most prominent Federal programs supporting increased resilience in buildings, both in anticipation of and following disaster events.

FEMA funding is available through several grant programs, including the Hazard Mitigation Grant Program (HMGP), the Flood Mitigation Assistance Program, and the new Building Resilient Infrastructure and Communities (BRIC) program. Per DRRA amendments, BRIC replaces the discontinued Pre-Disaster Mitigation (PDM) Program and addresses the new DRRA priorities described above. In general, states are eligible to receive FEMA funds contingent upon FEMA review and approval of their state mitigation program. States can also become eligible to receive additional funds under the grant programs if they earn approval of an enhanced plan demonstrating their ability to manage increased funding in pursuit of mitigation goals. As of April 2020, 15 states have earned this approval.[86]

HUD and EPA are examples of additional Federal agencies that support building resilience through programs and financial assistance targeting modern building codes. HUD offers housing and development assistance across the United States, with a mission to, "create strong, sustainable, inclusive communities and quality affordable homes for all."[87] To support these goals, HUD provides disaster relief resources. HUD's Community Development Block Grants (CDBG) aim to provide a more resilient community through infrastructure development, code enforcement, community facilities, housing rehabilitation, and public services, among other key areas.[88] The Environmental Protection Agency's (EPA) administers several complementary programs funded under BIL and IRA, in particular their Greenhouse Gas Reduction Fund and Climate Pollution Reduction Grants, which are broad initiatives supporting energy, climate and resilience planning, and with the potential to support the advancement of building energy codes across states and communities, as well as related training and implementation needs.

Building Codes and Hazard Risk Mitigation

Hazard risk assessment broadly refers to the methods used to quantitatively evaluate the potential impact of a hazard. The particular risk a community faces is a function of probability of exposure to a given hazard, its vulnerability, and the value of the elements at risk. As delineated in the equation below, hazard risk assessment can be applied to a single building, across the entire building stock, and for a community at large.

$$\boldsymbol{Risk} = Hazard \;\; x \;\; Vulnerability \;\; x \;\; Exposure$$ *(Hazard risk equation)*[89]

[86] FEMA, "Hazard Mitigation Plan Status," FEMA website, updated February 24, 2021, https://www.fema.gov/emergency-managers/risk-management/hazard-mitigation-planning/status. Accessed November 14, 2023.

[87] HUD, "Mission," HUD website, accessed March 29, 2024, https://www.hud.gov/about/mission

[88] HUD, "Community Development Block Grant Program," HUD website, updated March 8, 2024, https://www.hud.gov/program_offices/comm_planning/cdbg

[89] Ross, R. (2012), Guide for Conducting Risk Assessments, Special Publication (NIST SP), National Institute of Standards and Technology, Gaithersburg, MD, https://doi.org/10.6028/NIST.SP.800-30r1. Accessed November 14, 2023.

Hazard risk reflects the probability of experiencing a given extreme weather event. Vulnerability reflects the susceptibility of a structure to fail under stress. The vulnerability of a building is driven by its physical characteristics, such as its age, structural properties, material selection, and design quality. The exposure variable describes the value of a given element (e.g., building, people, monetary cost). The equation provides a useful framework to understand how the growing impact of weather and climate events on the Nation's building stock. The framework can also be used to assess the impact of mitigation measures, such as updated building codes. Building codes establish design requirements to protect life safety and minimize property damage against natural hazards and disaster events.

Natural Hazards and Climate Risk

As recognized by FEMA, communities face a variety of different threats and hazards that implicate buildings (Table 3). Building codes and other zoning requirements reflect the potential risk of these hazards and threats. These standards are updated accordingly to protect against the evolving hazards communities are likely to experience due to climate change.

Table 3: Example Threats and Hazards by Category; Source: FEMA[90]

Natural		Technological	Manmade
Avalanche	Hurricane	Hazardous materials release	Biological
Drought	Tornado	Industrial accident	attack
Earthquake	Tsunami	Pipeline explosion	Cyber attack
Epidemic	Winter storm	Urban conflagration	Explosives
Flood	Heatwave	Utility Disruption	attack

Climate change is altering the impact of natural hazards, resulting in more frequent and intense extreme weather- and climate-related events.[91] Driven by the anthropogenic emissions, a warming global climate will lead to stronger storms, more precipitation, and on average, hotter temperatures. The increasing intensity and consequential impact of heatwaves is not only the result of higher extremes, but also of hotter nighttime temperatures as shown in Figure 8.

[90] Threat and Hazard Identification and Risk Assessment (THIRA) and Stakeholder Preparedness Review (SPR) Guide. (2018). United States: Homeland Security. https://www.fema.gov/sites/default/files/2020-04/CPG201Final20180525.pdf. Accessed March 8, 2024.

[91] Reidmiller, David R., et al. "Impacts, risks, and adaptation in the United States: Fourth national climate assessment, volume II." (2017).

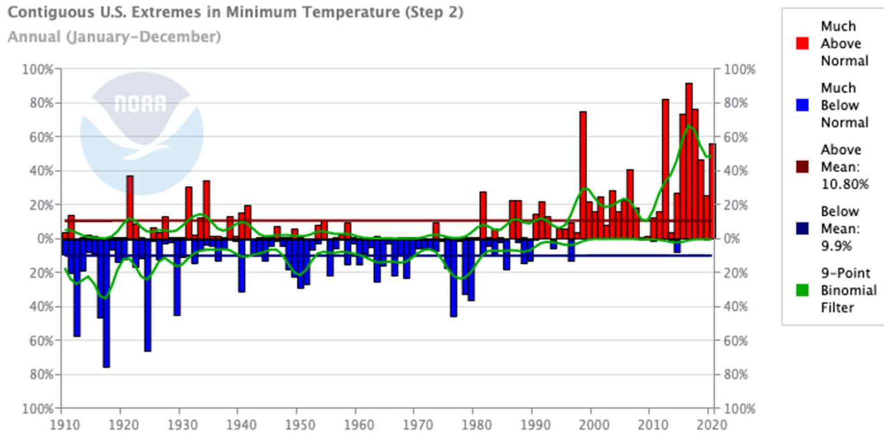

Figure 8: Annual rise in extreme minimum temperatures in the contiguous U.S.[92]

Summer nights have warmed at nearly twice the rate of summer days; the rise in nighttime temperatures exacerbates the public health risk, as body's' are less able to seek relief by cooling down.[93] Changing temperature conditions call for building codes— energy codes specifically—to adapt to future risks.[94]

Changing climatic conditions place greater stress on infrastructure, communities, and the surrounding environment. Extreme weather- and climate-events that overlap across time and space can produce compound extreme events that can be greater than the sum of the parts.[95] For example, simultaneous heat and drought can result in wildfires of much greater consequence; heavier rainfall from one event may cause more significant flooding from subsequent events.

Secondary Impacts to Building Energy Services

Hazards may stem from acute disaster events or more prolonged incidences, such as heatwaves. The intersection of multiple hazards can induce secondary, cascading impacts beyond the immediate disaster event. Compound and cascading events present greater risk to buildings and energy infrastructure systems. A list of hazards and the secondary impacts can be found in

[92] NOAA National Centers for Environmental information, Climate at a Glance: National Time Series, published June 2021, retrieved on June 30, 2021, from https://www.ncdc.noaa.gov/cag/.

[93] U.S. Centers for Disease Control and Prevention (CDC), National Environmental Public Health Tracking Network, https://www.cdc.gov/nceh/tracking/topics/ClimateChange.htm. Accessed November 14, 2023.

[94] Zakreski, Judy. "Adapting Building Standards to Changing Weather Risks." *ICC*, 17 Feb. 2021, https://www.iccsafe.org/building-safety-journal/bsj-dives/adapting-building-standards-to-changing-weather-risks/. Accessed November 14, 2023.

[95] Kopp, Robert, et al. "Potential surprises–compound extremes and tipping elements." *Climate Science Special Report: Fourth National Climate Assessment*, Volume 1. (2017). https://science2017.globalchange.gov/chapter/15/. Accessed November 14, 2023.

Table 4 below. These secondary risks are the predominant factors that contribute to property damage, negative health outcomes, and mortality following the initial weather disruption.

Table 4: Primary Natural Hazard and Secondary Building Impacts (adapted from BTO presentation)[96]

	Flooding	Hurricane	Tornado	Severe Thunderstorm	Earthquake	Winter storm/ ice storm	Wildfire	Urban Fire
Fire entry							x	x
Structural Damage	x	x			x	x	x	x
Damaged Equipment/ Electronics	x	x	x	x	x			
Burst Pipes						x		
Moisture damage	x	x		x		x		
Carbon Monoxide Poisoning		x			x	x	x	
Mold/ Bacterial Growth	x	x	x					
Indoor Air Quality		x	x		x	x	x	x
Ice Dams						x		
Loss of Power	x	x	x	x	x	x	x	x

Maintaining functional building energy systems during and after extreme temperature events is critical to safeguarding its occupancy, habitability, and continuity of operations. Building energy codes provisions directly address this energy-resilience nexus, but the need to maintain functional building systems transcends to all types of natural hazards covered by building codes at large.

Table 5: How Buildings Fail During Energy Outages: Examples of Secondary Impacts

Building failures elevate health risks, as captured in the below: • Food and medicine spoilage; • Inoperability of medical equipment; • Exposure to air contaminants; • Elevator outages and water delivery in high-rise apartments; • Unsafe thermal conditions (heat stroke/hypothermia); and • Increase of mold, bacterial, and mildew.
Depending on the subsector, commercial building failures can result in loss of: • Retail and offices—loss of inventory, business interruptions, and equipment damage. • Critical community lifelines—operation of hospitals, supermarkets, first responders, communication networks, and water treatment facilities.

Impacts due to energy loss can persist of months, even years, following a disaster event as communities wait for disaster recovery support. Building codes can be updated to more

[96] Mills, Evan. "Rugged, Resilience Residences," Briefing for DOE BTO, April 22, 2013.

effectively set design requirements that address secondary hazards from energy loss. Rebuilding to the latest building code ensures that homes are less vulnerable to future hazards.

Disaster Costs and the Value of Building Codes

Since 2000, the United States has experienced 286 weather and climate disasters where damages exceeded $1 billion (Figure 9).[97] Annual disaster costs have steadily increased over the decades, with the average annual cost exceeding $120 billion over the last 5 years. The growing cost of weather and climate disasters can be attributed to the increase in exposure (i.e., more assets at risk) and vulnerability (i.e., diminishing resistance to natural hazards) of the Nation's building stock.[98]

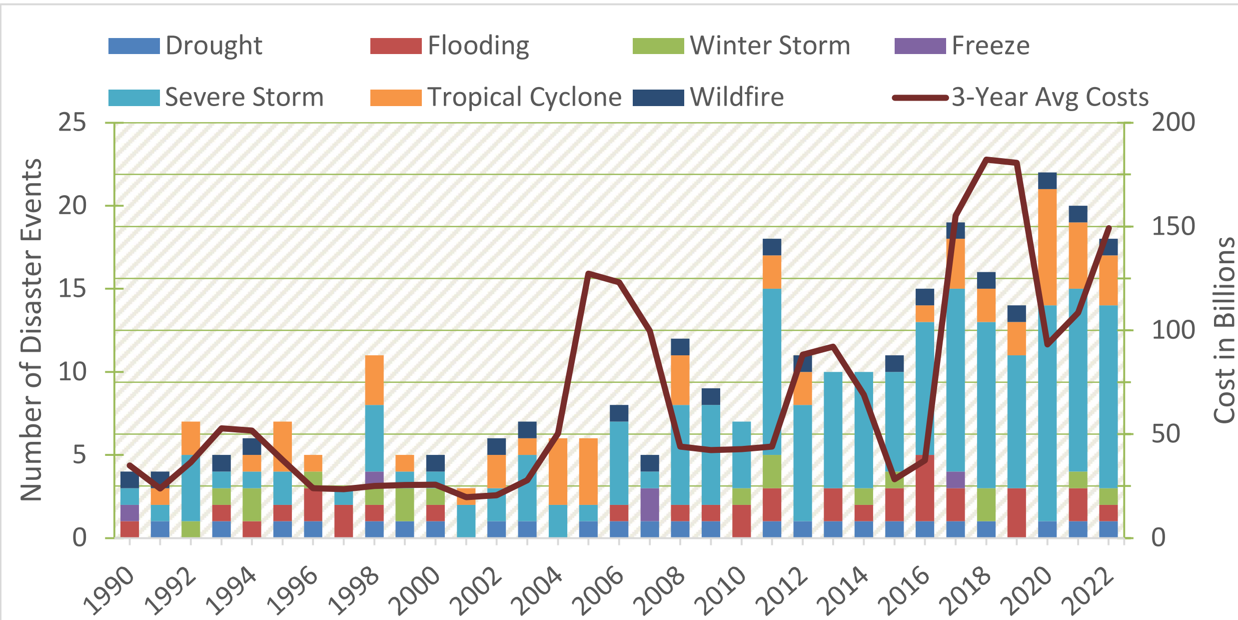

Figure 9: Billion-dollar weather and climate disasters that impacted the United States.[99]

The rise in disaster costs can also be attributed to the increased occurrence of compound extremes as described above. Overlapping events or concurrent hazard risks further present challenges most communities are unprepared for. Building code updates are a critical opportunity to improve design requirements that mitigate emerging risk profiles. Yet states should target adopting the latest model energy codes for their benefits to be realized, while limiting amendments that may reduce these benefits.

---

[97] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73. Accessed November 14, 2023.

[98] Smith, Adam B. "2023: A historic year of U.S. billion-dollar weather and climate disasters." *Beyond the Data*, NOAA National Centers for Environmental Information, 8 Jan. 2024. https://www.climate.gov/news-features/blogs/beyond-data/2023-historic-year-us-billion-dollar-weather-and-climate-disasters. Accessed May 7, 2024.

[99] Op. cit., NCEI, 2023.

Hazard mitigation impact analyses are a type of assessment used to compare the cumulative value of avoided damage losses between different model code editions. Two notable studies, FEMA's "Building Codes Save: A Nationwide Study," and the National Institute of Building Science's (NIBS) "Mitigation Saves" report, have garnered significant attention showing that modern codes improve building resilience to natural disasters.

The 2018 NIBS study conducted an extensive benefit-cost analysis of the benefits from several sets of mitigation measures for four types of hazards (e.g., flooding, hurricanes, earthquakes, and fires at the wildland-urban interface or WUI). [100] The evaluation determined that a benefit-cost ratio (BCR) of $11:1 is achieved relative to a 1990-era design by adopting contemporary building code requirements in residential and commercial buildings.[101] The analysis and findings validate the resounding value of building codes. NIB's *Mitigation Saves* has served as a vital study to promote building codes as foundational part of both national and community resilience.

The 2020 *FEMA Building Codes Save* study uses over a decade of research and data to quantify the associated physical and economic losses from flooding, hurricane wind, and earthquakes that hazard-resistant building codes could mitigate. The results estimate that the cities and counties with modern building codes will save $3.2 billion per year in annual losses avoided by 2040, when compared to jurisdictions without modern codes. Cumulatively, these savings would add up to over $130 billion in avoided property damage based on forecast construction rates.[102]

Multiple additional studies have quantified the benefit of natural hazard mitigation at the regional, state, and community scale because of adopting and implementing specific aspects of modern building codes:

- According to an Insurance Institute for Business & Home Safety (IBHS) 2018 study, well-enforced building codes reduced the losses associated with Hurricanes Irma, Maria, and Harvey in 2017. In Florida, 80% of the homes built to recent codes (post Hurricane Andrew) experienced significantly less damage during Hurricane Irma compared to homes meeting earlier and less stringent building standards. [103]

[100] NIBS, *Natural Hazard Mitigation Saves: 2018 Interim Report* (Washington DC: NIBS), 2018. https://www.nibs.org/news/national-institute-building-sciences-issues-interim-report-value-mitigation. Accessed May 7, 2024.

[101] Specified in the study as the 2018 ICC codes.

[102] FEMA, "Building Codes Save: A Nationwide Study of Loss Prevention," (Washington DC: FEMA), 2020. https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-save-study.

[103] IBHS, "*Rating the States: 2018* https://ibhs.org/wp-content/uploads/member_docs/Rating-the-States-2018_IBHS.pdf. Accessed November 14, 2023.

- Research following Hurricane Charley (2004) indicated a 60% decrease in the frequency of residential damage and a 42% decrease in cost claims.[104]
- After Hurricane Katrina, coastal communities surveyed in Alabama, Louisiana, and Mississippi, went from 36 percent enforcing older versions of the International Residential Code (IRC) to 90% enforcing the updated 2012 IRC.[105]

The examples summarized above illustrate that building codes can contribute to enhanced building resilience. While future building code updates can enable more robust hazard-resistance, many states have yet to adopt the latest model code. Furthermore, building code updates do not apply to existing building stock that was constructed to meet previous code editions.

Resilience within Building Codes

Building codes have evolved as a tool to catalyze market transformation used by states and municipalities to achieve energy and environmental goals. The code development process is an active, inclusive, and forward-looking system—a necessity to keep pace with building technology innovations and advanced construction practices.

Building codes serve as a viable framework to operationalize energy resilience because:

- The industry model code development process lends itself to the shifting building design trends and construction practices. As the model codes are updated on a three-year cycle, they can incorporate improvements resilience strategies, as well as corresponding updates made to reference standards, hazard maps, and associated mitigation measures.
- The emerging concept building resilience requires learning and applying lessons from the range of hazards, natural disasters and changing weather patterns experienced in both the United States and internationally.
- Building codes are the primary determinant to predict expected losses and other estimates used within the insurance industry.

Building energy codes:

- Are designed to efficiently maintain indoor thermal conditions based on the regional climates that reflect average annual heat and cooling needs.
- Mediate interactions between buildings, distributed energy resources (DERs), and the electric grid.

[104] IBHS, "Hurricane Charley Report", August 13, 2004. https://ibhs.org/wp-content/uploads/member_docs/Hurricane-Charley-Natures-Force-vs-Structural-Strength-Executive-Summary_IBHS.pdf. Accessed November 14, 2023.
[105] IBHS, "Katrina: 10 Years Later," August 2015. https://ibhs.org/wp-content/uploads/member_docs/Katrina-10-Years-Later_IBHS.pdf. Accessed November 14, 2023.

- Inform requirements for building material characteristics and design standards that protect against flammability, moisture infiltration, humidity control, and air quality considerations.

The next section offers an in-depth discussion as to how energy efficiency and resilience can be applied through building energy codes.

IV. The Nexus of Building Energy Efficiency and Resilience

The intersection of building energy efficiency and resilience is evident across all three stages of a disaster event. The benefits of energy efficient buildings are realized over its lifetime, providing benefits that scale from the building level to the broader community. Energy efficiency strategies that likewise enhance building resilience support two foundational objectives of building codes. Building codes are developed to withstand a multitude of natural hazards and extreme weather events. Energy efficiency measures at the building level can provide a variety of direct and indirect benefits.

Table 6: Resilience Benefits of Energy Efficiency; Source: ACEEE (2016)[106]

Benefit type	Energy efficiency outcome	Resilience benefit
Emergency response and recovery	Reduced electric demand	Increased reliability during times of stress on electric system and increased ability to respond to system emergencies
	Backup power supply from combined heat and power (CHP) and microgrids	Ability to maintain energy supply during emergency or disruption
	Efficient buildings that maintain temperatures	Residents can shelter in place as long as buildings' structural integrity is maintained.
	Multiple modes of transportation and efficient vehicles	Several travel options that can be used during evacuations and disruptions
Social and economic	Local economic resources may stay in the community	Stronger local economy that is less susceptible to hazards and disruptions
	Reduced exposure to energy price volatility	Economy is better positioned to manage energy price increases, and households and businesses are better able to plan for future.
	Reduced spending on energy	Ability to spend income on other needs, increasing disposable income (especially important for low-income families)
	Improved indoor air quality and emission of fewer local pollutants	Fewer public health stressors
Climate mitigation and adaptation	Reduced greenhouse gas emissions from power sector	Mitigation of climate change
	Cost-effective efficiency investments	More leeway to maximize investment in resilient redundancy measures, including adaptation measures

Resilient systems can absorb the impacts of adverse weather events, disasters, and stresses to energy infrastructure that could otherwise cascade into major disruptions. In addition to mitigating risk, resilient buildings provide energy savings during normal operation.

Building Energy Codes that Support Resilience

The ORNL workshop reinforced the idea that building energy codes represent a key opportunity to enhance resilience in buildings, and that the energy-resilience nexus must consider the inherent relationship between buildings and the grid. The workshop also recognized that many resilience objectives are addressed in some form by building codes today, which can serve as a basis for examining energy-resilience impacts and potential future actions.

The intersection of building energy efficiency and resilience is evident across all three stages of a disaster event. The benefits of energy efficient buildings are realized over its lifetime, providing benefits that scale from the building level to the broader community. Energy efficiency strategies that likewise enhance building resilience support two foundational objectives of building codes. Building codes are developed to withstand a multitude of natural

[106] ACEEE, *Enhancing Community Resilience through Energy Efficiency*, David Ribeiro, October 2, 2015, https://www.aceee.org/research-report/u1508. Accessed November 14, 2023.

hazards and extreme weather events. Energy efficiency measures at the building level can provide a variety of direct and indirect benefits.

Table 6 above highlights several co-optimized benefits of energy efficiency and resilience. Table 7 below illustrates specific energy-resilience contributions embedded in current model energy code provisions.

Table 7: Select Energy Code Provisions From the 2018 IECC That Support Resilience[107] ***(2019).***[108]

Selected Code Topic	Relevant Sections (2018 IECC)	Supported Resilience Strategy	Relevant Hazards
Insulation	C402.2, R402.2	▪ Passive survivability ▪ Reduced energy burden ▪ Reduced grid impact ▪ Reduced ice-dams ▪ Reduced condensation, limiting mold and mildew	▪ Extreme heat ▪ Extreme cold ▪ Snow storms ▪ Social resilience ▪ Secondary impacts to all hazards
Walk-In Coolers and Freezers	C403.10	▪ Food safety/preservation	▪ Extreme heat ▪ Secondary impacts to all hazards
Daylighting	C402.4.1	▪ Passive survivability ▪ Reduced grid impact	▪ Extreme heat ▪ Secondary impacts to all hazards
Window-to-Wall Ratios	C402.4.1, R402.3	▪ Passive survivability ▪ Impact vulnerabilities	▪ Extreme heat ▪ Extreme cold ▪ Hurricanes ▪ Tornadoes
Solar Heat Gain Coefficient	C402.4.3, R402.3.2	▪ Passive survivability ▪ Reduced grid impacts	▪ Extreme heat ▪ Secondary impacts to all hazards
Solar Reflectance of Roof	C402.3	▪ Urban heat island ▪ Passive survivability	▪ Extreme heat ▪ Secondary impacts to all hazards
Air Leakage	C402.5, R402.4	▪ Contaminants (secondary to wild-fire, earthquake, etc.) ▪ Mold and mildew (secondary to flooding, hurricane, extreme cold, etc.)	▪ Secondary impacts to all hazards
Pipe Insulation	C404.4, R403.4	▪ Passive survivability ▪ Reduced energy burden	▪ Extreme cold ▪ Drought ▪ Social resilience
On-Site Renewable Energy	C406.5, Appendix CA, Appendix RA	▪ Contribute to distributed generation ▪ Facilitates islandability	▪ Secondary impacts to all hazards

Table 7 highlights energy efficiency measures included in model energy codes today, referencing the applicable code sections and how each strategy supports increased resilience and is responsive to relevant hazards. It's important to consider that while different building efficiency measures may lead to the same overall energy performance outcomes (e.g., annual whole-building energy consumption), various energy efficiency strategies do not necessarily equate to the same resilience benefits. The following section expands on some of the specific

[107] International Code Council. *2018 International Residential Code; 2018 International Building Code*. 2018. ICC: Washington, DC. https://codes.iccsafe.org/. Accessed March 7, 2024.

building systems and design features found within energy codes, as outlined in the table above, and adds discussion around some of the anticipated energy-resilience outcomes.

Building Envelope Systems

The envelope of a building (IECC sections C402 and R402 for commercial and residential buildings, respectively) is the primary means of addressing passive survivability, but also contributes to many other resilience benefits. Acting as a thermal, physical, and moisture barrier between interior and exterior environments, efficient building envelopes provide a variety of secondary benefits, including structural durability, moisture control, and natural daylighting. The building envelope, which includes the walls, windows, roof, and foundation, impacts approximately 30% of the heating and cooling load efficiency of residential and commercial buildings.[109] Design considerations for insulation levels, window-to-wall ratios, window characteristics, and air leakage rates and a variety of other envelope attributes are typically regulated by building energy codes and can directly support resilience design strategies.

Insulation within walls and under the roof (C402.2 and R402.2) provide not only thermal resistance to prevent heat loss and gain, but also increased structural support against high-velocity winds and heavy snowfall.[110] The same concept applies to window design (C402.4 and R402.3) in that double- and triple-pane windows constructed with metal framing not only reduce heat transmission and HVAC energy use, but strengthen a building's exterior against hurricane-like conditions.[111]

The proper construction of a building envelope, specifically moisture and air barriers (C402.5 and R402.4), also contributes to the energy and resilience of a building. Uncontrolled air leakage can be responsible for up to 30% of the energy consumption for a building and is one of the most cost-effective approaches to reduce energy use.[112] Air leakage is often a result of gaps between various connections within the envelope and protrusions. From a resilience perspective, a building envelope designed to the latest code for energy efficiency helps maintain internal air temperatures.[113] It also helps ensure proper moisture control that can be a product of physical infiltration of rain or precipitation, or condensation between surfaces due

[109] U.S. Department of Energy, Better Buildings Solution Center, "Building Envelope," https://betterbuildingssolutioncenter.energy.gov/alliance/technology-solution/building-envelope. Accessed November 14, 2023.

[110] Roels, Staf, and Jelle Langmans, "Highly insulated pitched roofs resilient to air flow patterns: Guidelines based on a literature review," *Energy and Buildings* 120 (2016): 10–18.

[111] U.S. Department of Energy, Building Technologies Office, "Hurricanes and High Winds Overview." https://basc.pnnl.gov/information/hurricanes-and-high-winds-overview. Accessed April 11, 2022.

[112] U.S. Department of Energy, "Why Energy Efficiency Upgrades," https://www.energy.gov/eere/why-energy-efficiency-upgrades. Accessed November 14, 2023.

[113] Franconi, E, E Hotchkiss, T Hong, M Reiner et al. 2023. Enhancing Resilience in Buildings through Energy Efficiency. Richland, WA: Pacific Northwest National Laboratory. PNNL-32737, Rev 1. https://www.energycodes.gov/sites/default/files/2023-07/Efficiency_for_Building_Resilience_PNNL-32727_Rev1.pdf

to uncontrolled air movement through the assembly, particularly when combined with lack of dehumidification.

Moisture buildup can lead to a variety of different health and safety issues when building material cannot dry. These issues are amplified during a loss of power as HVAC systems cannot operate to remove indoor humidity. Excessive moisture can lead to health risks due to mold and bacterial growth, and intrusion of other particulates and allergens.[114] Following Hurricane Katrina, a CDC study found visible mold growth in 46% of the homes surveyed[115]—and researchers expressed concerns about possible effects of mold growth associated with Hurricane Harvey, as well.[116]

In cold climates, higher levels of insulation and air tightness can prolong and enhance the passive survivability of a building, or commonly recognized as the ability for occupants to shelter-in-place during and following a disaster event. During a storm-induced outage in December 2013, a community of homes built to the Passive House[117] standard was able to maintain interior temperatures of at least 58 degrees for four days despite outdoor temperatures being below zero.[118]

Designed with abundant insulation and an airtight envelope, these homes are estimated to reduce a home's energy use by 75 to 90%. Achieving such levels of performance and

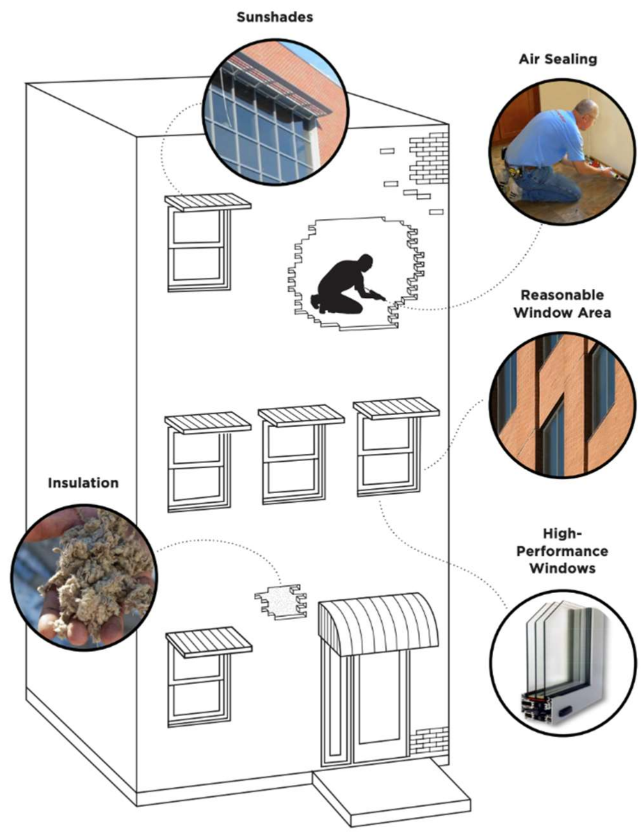

Figure 10: Building Properties of a High-Performance Building. Source: Urban Green Council (2014).[102]

[114] William J. Fisk, "Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures," *Building and Environment* 86 (2015): 70–80.
[115] Centers for Disease Control. "Health Concerns Associated with Mold in Water-Damaged Homes After Hurricanes Katrina and Rita," *MMWR Weekly*, January 20, 2006. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5502a6.htm. Accessed April 11, 2022.
[116] Chow, Nancy A., et al. "Hurricane-Associated Mold Exposures Among Patients at Risk for Invasive Mold Infections After Hurricane Harvey—Houston, Texas, 2017." *Morbidity and Mortality Weekly Report* 68(21) (2019): 469-473. https://www.cdc.gov/mmwr/volumes/68/wr/mm6821a1.htm. Accessed March 8, 2024.
[117] PHIUS, "Certification for Building Projects," https://www.phius.org/certifications. Accessed November 14, 2023.
[118] Tim King, "Passive House is anything but passive," *Green & Healthy Maine Homes*, October 15, 2016. https://greenmainehomes.com/blog/passive-house-is-anything-but-passive. Accessed November 14, 2023.

energy load reductions mean the dwelling can often remain livable based on passive internal heat gains, such as human occupants, heat gain through strategically placed fenestration and/or thermal mass. In addition, the home can function on a relatively small backup power generation system, either through traditional gas-powered generators or by 'islanding' via onsite PV combined with an energy storage system.

A study by Rocky Mountain Institute analyzed such a scenario for range of five building vintages: typical homes built in the 1950s and 1980s, a home that meets 2009 IECC Code, a home built to U.S. Passive House standards, and a net-zero energy ready home. As shown in Figure 11: Modeled indoor temperature of five building types. Source: RMI (2020)., the measurements of indoor air temperatures during a power outage under extreme cold conditions demonstrated the superior performance of buildings designed to the latest energy codes and above-code programs, including the U.S. Passive House standard and DOE's Zero Energy Ready Homes program.[119] The enhanced performance can be attributed to design requirements that call for better airtightness, insulation, and windows.

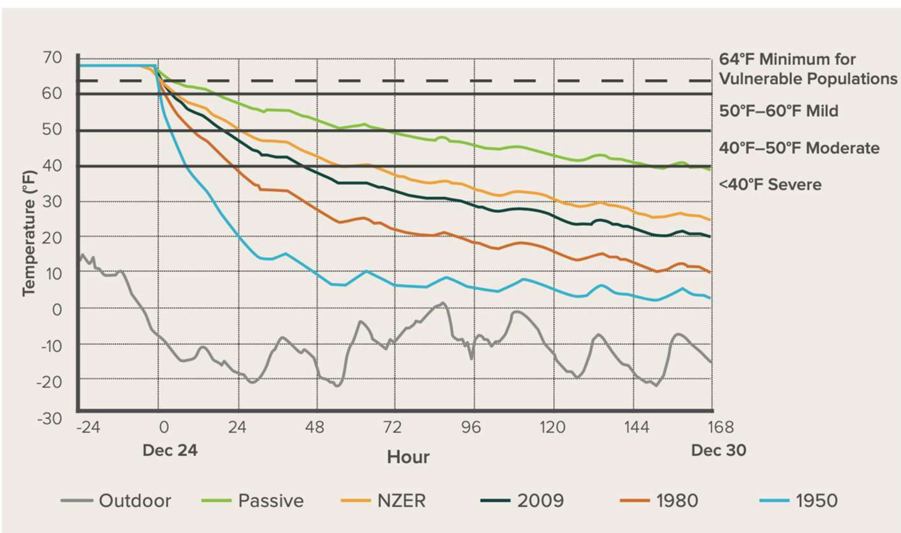

Figure 11: Modeled indoor temperature of five building types. Source: RMI (2020).[110]

In response to building performance following the loss of power from Superstorm Sandy, the U.S. Green Building Council conducted a study to investigate the passive survivability of various building designs in New York City.[120] The study confirmed that high-performance buildings perform dramatically better than the 'average' building in both heatwaves and cold spells. The study further reinforced that certain building types, notably single-family detached homes, are more sensitive to temperature fluctuations without power. Ongoing research has shown that

[119] Sneha Ayyagari, Michael Gartman, and Jacob Corvidae, "Hours of Safety in Cold Weather: A Framework for Considering Resilience in Building Envelope Design and Construction," *RMI*, 2020, https://rmi.org/insight/hours-of-safety-in-cold-weather/. Accessed November 14, 2023.
[120] Urban Green Council, *Baby It's Cold Inside*, February 2014, https://www.urbangreencouncil.org/baby-its-cold-inside/. Accessed November 14, 2023.

the impact of energy efficiency measures on thermal resilience can vary greatly by building characteristics and climate.[121] In the *Baby its Cold Inside* NYC study, all-glass building constructed to older building energy codes led to dangerous indoor air temperatures during heat waves. Research has shown that certain building efficiency measures, such as increased wall insulation, can adversely increase indoor overheating because of decreased rate of nighttime cooling.[122] The specific conditions under which efficiency measures could yield negative resilience outcomes is a particular area that requires further research.

HVAC and Hot Water System Design

The design of a proper HVAC system supports grid resilience through greater load control and provides a variety of secondary occupant benefits. HVAC systems—heating, ventilation, and air conditioning—accounts for about 35% of building energy use.[123] Building energy codes direct the design, sizing, and performance of HVAC systems based on building size and climate zone. HVAC requirements direct the conditioning of indoor space, ensuring proper temperature control and ventilation for fresh air.

Electric heat pumps are a particular technology that offer considerable energy savings, while providing to grid flexibility benefits. Heat pumps are a more efficient replacement for traditional air conditioners and are also capable of operating in a reverse cycle for heating purposes. Advances in air conditioning technology enable more efficient control of indoor comfort levels. By isolating relative humidity or moisture from traditional cooling loads, indoor conditions can be maintained using as much as 30% less energy.[124] Such systems are particularly useful in hot and humid climates to address peak cooling demand periods on the grid. Heat pumps can also provide grid flexibility benefits by responding to grid needs and employing strategies such as pre-cooling a building to avoid operating during times of peak demand.

Hot water heat pumps are another opportunity to improve energy performance, while providing grid flexibility. Heat pump water heaters (HPWHs) rely on heat pump technology to heat water that is held in a typical storage tank. HPWHs use 50–75% less electricity than an electric resistance water heater.[125] Unlike other electric water heaters, the energy load profile of HPWHs can be modified to reduce strain on the grid. When enabled as a grid-integrated

---

[121] Kaiyu Sun, Michael Specian, and Tianzhen Hong, “Nexus of thermal resilience and energy efficiency in buildings: A case study of a nursing home,” *Building and Environment* 106842 (2020).
[122] William J. Fisk, “Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures,” *Building and Environment* 86 (2015): 70–80.
[123] U.S. Department of Energy, “Chapter 5: Increasing Efficiency of Building Systems and Technologies,” in *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*, September 2015. https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf. Accessed November 4, 2023.
[124] Omar Abdelaziz, *Primary Energy Efficiency Analysis of Different Separate Sensible and Latent Cooling Techniques*, ORNL Building Technologies Research and Integration Center, Oak Ridge, TN, 2015. https://www.osti.gov/servlets/purl/1265724. Accessed March 8, 2024.
[125] Bethany Sparn, Jeff McGuire, *Increasing the Number of Installed Residential Heat Pump Water Heaters in the USA Through Improved Technology and Utility Programs.* 2021. National Renewable Energy Laboratory: Golden, CO. doi:10.1007/s40518-021-00177-5.

water heater (GIWH), they can be programmed to operate during periods of low energy demand and/or high renewable energy generation, instead of peak demand periods. Under such conditions, GIWHs act as a form of thermal energy storage as represented in Figure 12 below.

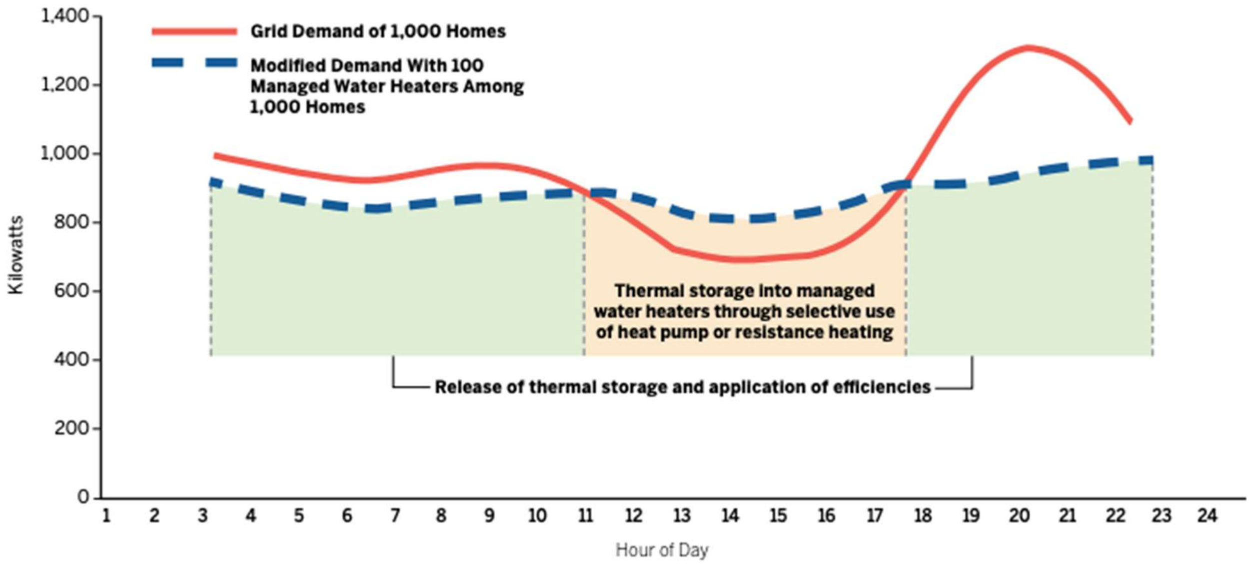

Figure 12: Depiction of GIWH grid benefits as thermal storage. Source: Du Plessis (2016).[126]

The control of indoor air quality via mechanical ventilation (C403 and R403) mitigates the infiltration of unwanted contaminants from wildfire smoke, chemical releases, and other unhealthy fumes. Balanced air mechanical systems improve more efficient distribution of air throughout a building and enable greater control of cycling air to and from outdoor spaces.[127] Controlled ventilation has received particular attention in recent years due to the increase in wildfires.[128] High-performance building envelopes constructed with higher insulation levels and minimum air leakage can cause unintended air flows, such as backdrafting from combustion equipment (e.g., fireplaces, furnaces, stoves, and water heaters).[129] It's also critical to consider the interrelated effects building envelope and mechanical systems, particularly with tight envelopes and the ability to maintain comfort and healthy and levels of indoor air quality. As an example, coordinated mechanical and energy efficiency requirements embedded in the

---

[126] DuPlessis, S. (2016, February). Grid responsive GeoSpring HPWH [Presentation to ACEEE 2016 Hot Water Forum]. GE Appliances. https://www.aceee.org/sites/default/files/files/pdf/conferences/hwf/2016/DuPlessis_Session5A_HWF16_2.23.16.pdf. Accessed March 8, 2024.

[127] Carl Ian Graham, PE, "High-Performance HVAC," *Whole Building Design Guide*, https://www.wbdg.org/resources/high-performance-hvac. Accessed November 14, 2023.

[128] Washington State Department of Health, "Improving Ventilation and Indoor Air Quality during Wildfire Smoke Events," DOH 333-208, August 2015, https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs//333-208.pdf. Accessed November 14, 2023.

[129] U.S. Department of Energy, Building Technologies Office, *Insulation: A Guide for Contractors to Share with Homeowners*, PNNL-20972, May 2012, https://www.energy.gov/sites/prod/files/2013/11/f5/insulation_guide.pdf

residential code (IRC) require mechanical ventilation when envelope air infiltration rates fell below 5 air changes per hour (ACH50) (C403.2 and R403.6).

Recent energy code proposals have targeted notable changes to HVAC design criteria that target improved waste heat recovery, reduced losses within duct systems, and mechanically controlled air ventilation.[130] These concepts, combined with broader advances in HVAC system technology and quality installation methods, provide both energy savings and ancillary resilience benefits through enhanced moisture control, thermal comfort, and indoor air quality.

Control Systems and Dynamic Load Shifting

Building performance, designed to operate as part of the complex energy system, is invariably tied to the reliability of the grid. The performance of the electric grid is sensitive to when and where energy is consumed, particularly in residential and commercial buildings, which combined make up over 75% of average annual electricity consumption.[131] The value of energy efficiency—the avoided cost to the system of producing and delivering electricity—is time-varying; building energy efficiency provides greater value when demand is reduced during peak periods as opposed to overnight when there is less demand. Grid-enabled technologies are a particularly important resource to balance the growing variability in power supply of renewable energy, notably wind and solar. The benefits of grid flexibility are illustrated in the figure below.

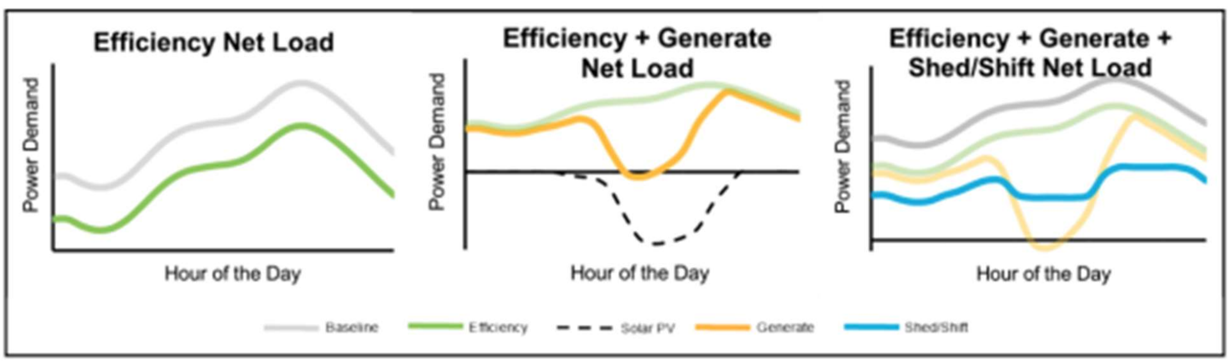

Figure 13: Illustration of the multiple forms of demand flexibility. Source: U.S. DOE and NASEO.[132]

Building energy code updates are being targeted to aid the adoption of grid-enabled building technologies that support resilience benefits. Connectivity between building loads and the utility grid is a critical component of grid-optimization to unlock grid flexibility. Smart appliances and thermostats enable interactions between building loads and grid operators that can be called on during peak demand periods where excessive demand can lead to power outages.

---

[130] Kimberly Cheslak, "The Top 5 Energy Efficiency Proposals for the 2021 IECC," *Institute for Market Transformation*, May 21, 2019, https://www.imt.org/the-top-5-energy-efficiency-proposals-for-the-2021-iecc/. Accessed November 14, 2023.

[131] U.S. Department of Energy, Building Technologies Office, "About the Building Technologies Office," https://www.energy.gov/eere/buildings/about-building-technologies-office. Accessed November 14, 2023.

[132] NASEO, "Grid-interactive Efficient Buildings: State Briefing Paper" October 2019.

Advanced metering can also enable the co-optimization of building energy systems with utility programs. Some of these strategies, such as controlled electrical receptacles, have already been incorporated into Standard 90.1 (Section 8.4.2), while others such as demand response-capable thermostats and water heaters have more recently been proposed.[133] Resilience benefits are achieved through everyday energy efficiency and grid optimization, and can be further amplified during a disruption by the ability to shift loads.

Additionally, smart sensors, controls, and management systems incorporate redundancy and diagnostics within building energy systems and can help identify potential issues before a catastrophic failure or hazard event. Fault detection sensors, which have been proposed for commercial energy codes, aid proactive mitigation and continued operation of HVAC equipment. Even simple devices such as smart plugs can reduce vampire loads associated with electronics in standby mode and protect against power surges.

Other forms of strategic load controls can establish critical load circuits so buildings can manage essential systems for operational capacity, such as load shifting during a low- or no-power event. Load control has resilience applications across multiple building types—for example, enabling hospitals to extend operational capabilities during a disaster event, supermarkets to maintain refrigeration and preservation of food, and disaster centers to conduct mission critical disaster management.[134] While critical load management is not required within building *energy* codes today, electrical codes address requirements for safe and effective load switching, where applicable, including transfer switches to prevent back-feeding power to the grid during onsite generation. FEMA has also developed guidance on the energy power management of critical facilities during hazard events.[135]

While automated controls, sensors, and communications devices improve interoperability between buildings and the grid, they also increase the complexity of buildings, leading to potential vulnerabilities. For example, smart devices present greater risk of cyberthreats and failures to communication networks.[136] Building managers may require additional training to properly operate automated building systems and related safeguards. These challenges must be considered in addition to the list of natural threats typically targeted by hazard mitigation programs.

---

[133] Several related proposals are pending approval and publication in the 2024 IECC.

[134] Gridwise Alliance, *Improving Electric Grid Reliability and Resilience: Lessons Learned from Superstorm Sandy and Other Extreme Events: Workshop Summary and Recommendations*, June 2013. https://www.energy.gov/sites/prod/files/2015/03/f20/GridWise%20Improving%20Electric%20Grid%20Reliability%20and%20Resilience%20Report%20June%202013.pdf. Accessed November 14, 2023.

[135] FEMA, "Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability," Sept. 2014, https://www.wbdg.org/FFC/DHS/femap1019.pdf. Accessed November 14, 2023.

[136] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, EERE Cybersecurity Multiyear Program Plan. May 2021. DOE: Washington, DC. https://www.energy.gov/sites/default/files/2021-06/EERE-Cybersecurity-Multiyear-Program-Plan-opt.pdf. Accessed April 11, 2022.

On-Site Generation and Energy Storage Systems

On-site energy generation and distributed energy resources (DERs)—in the form of gas generators, renewables, or battery storage—can supply backup power in the event of a power disruption. On-site photovoltaic systems (PVs), when combined with energy storage, can enable buildings to operate independently during a grid disruption. Although DERs help reduce carbon emissions and support renewable energy goals, DERs can increase the variability of demand on the grid, such as through rapid load ramping and discharge, affecting grid stability and overall system reliability. Adding storage helps address this problem and provides additional financial and resilience benefits. For example, storage can help manage peak loads and lower utility bills. Storage can also support resilience objectives by providing backup power for critical loads, such as heating and cooling, refrigeration, lighting, phone charging, and home health equipment.

As a result, communities are considering PV combined with storage as an important strategy to provide emergency power during an extended outage, merging energy and resilience goals. The approach creates local zones served by solar PV and storage systems co-located with emergency services (e.g., coordination centers, shelters, and kitchens), thereby localizing disaster support systems and mitigating risk through redundancy.[137]

Today, model building energy codes, including the IECC and Standard 90.1, can address renewable energy systems and DERs in both the prescriptive and performance compliance paths.[138] For prescriptive codes, *additional efficiency requirements* include both renewable and DER options that may be selected to meet the requirements of that section. For performance codes, energy modeling can be used to demonstrate limited tradeoffs between energy efficiency components and onsite renewable energy generation.[139] States and localities can also adopt IECC appendices that establish solar-readiness zones of commercial and residential buildings. These zones do not require PV installation, but equip buildings with the necessary space, circuitry, and wire chases to more readily enable future onsite PV installation. The new edition of California's building energy code (Title 24) requires onsite solar PV installation in certain situations, and ASHRAE 90.1 introduced on-site renewable energy requirements in its 2021 version.

Building Energy Resilience Metrics

Energy codes ensure buildings are cost-effective, healthy, and comfortable, and durable over their lifetime. As discussed in the previous sections, energy efficiency requirements, as enacted through energy codes, enhance building energy resilience. Building energy codes are an

---

[137] Carl Broomhead and Russell Carr, "Solar + Storage for Resiliency," ACEEE Summer Study of Energy Efficiency in Buildings, 2016, https://www.aceee.org/files/proceedings/2016/data/papers/11_1046.pdf. Accessed November 14, 2023.

[138] The prescriptive path sets requirements for each building component (e.g., insulation R-value), whereas the performance path sets an overall performance threshold that must be met using an energy simulation model.

[139] For example, at the time of writing, the commercial requirements of the IECC and Standard 90.1 cap renewable energy tradeoffs at five percent of the building's total energy budget under the performance path. In other instances, specific envelope 'backstops' must be adhered to, limiting excessive tradeoffs against any single building component.

established and readily adoptable mechanism to achieve enhanced energy resilience because they include prescriptive- and performance-based compliance options, consider a range of multi-faceted parameters (including both energy efficiency and resilience objectives), and can be adapted to further address building-grid integration challenges, such as the time-sensitive nature of energy usage and costs.

States and cities have already begun to implement performance-based requirements that reflect building-grid harmonization within energy codes. For example, California's 2022 Title 24 update uses three Energy Design Rating (EDR) metrics – source energy, energy efficiency, and total energy – where the EDR, total metric accounts for both solar electric generation and demand flexibility.[140] Washington state's energy code uses a combination of greenhouse gas emissions and site energy use as its metrics.[141] ASHRAE has the ability to include alternative analysis parameters in Standard 90.1 that can be utilized when evaluating flexible grid-integrated technologies based on a time-sensitive valuation of energy prices.[142]

In addition, DOE's recent research evaluated a set of metrics to determine which could potentially represent the resilience value that energy codes provide. These metrics were evaluated on their robustness, or the reliability of that metric. Some, such as the metrics to value occupant exposure to extreme temperatures (i.e., Standard Effective Temperature and Heat Index) were relatively robust, as they were fairly well-established industry standards. However, others like metrics to value property damage were considered low robustness due to inconsistencies with the data used to develop the metric. Results are shown in Table 8.

[140] California Energy Commission, "Section 100.1 – Definitions and Rules of Construction," in *Title 24: 2022 Building Energy Efficiency Standards*, 2022, https://www.energy.ca.gov/sites/default/files/2022-08/CEC-400-2022-010_CMF.pdf. Accessed March 29, 2024.
[141] Washington State Energy Code – Commercial 2021 Edition." January 2024. Washington State Building Code Council: Olympia, WA. https://sbcc.wa.gov/sites/default/files/2024-01/2021_WSEC_C_2ndEd_012824.pdf. Accessed March 29, 2024.
[142] This alternative was incorporated in the Standard 90.1-2022 Work Plan, providing the 90.1 development and consensus body the ability to evaluate flexible technologies in future Standards.

Table 8: Relative Robustness of Resilience Valuation Metrics. Source: U.S. DOE.[143]

Valuation Component	Data Source or Method	Relative Robustness	Opportunities for Improvement
Extreme temperature event identification	Ouzeau method	Medium	Standardize approach for selecting representative event
Joint probability of event with power outage	OE-417	Medium	Improve outage data assessment
Occupant exposure	SET and HI determined from simulation modeling	High	Correlate metrics to health impacts
Occupant damage	Gasparrini relative rate mortality curves	Medium	Further develop method and perform additional validation checks
Property damage	FEMA NRI data	Low	Base losses on data compiled from recent events
First costs	Energy codes costing algorithms	Medium	Consider existing building first costs as incremental for retrofit-ready projects
Benefit–cost ratio	Net present value	Medium	Improve robustness of input values

Building energy codes could be further amended to include additional performance metrics applicable to energy resilience. Building codes could foreseeably establish performance-based thresholds for continued operation under a power outage like how structures are designed to sustain specified structural loads. For example, energy codes could specify the number of hours a building must maintain livable indoor temperatures, or the number of hours a backup energy generation system must operate. Table 9 lists similar examples of metrics embedded within current building codes, including reference standards, that transcend efficiency and resilience.

[143] Franconi, E, E Hotchkiss, T Hong, M Reiner et al. 2023. Enhancing Resilience in Buildings through Energy Efficiency. Richland, WA: Pacific Northwest National Laboratory. PNNL-32737, Rev 1. https://www.energycodes.gov/sites/default/files/2023-07/Efficiency_for_Building_Resilience_PNNL-32727_Rev1.pdf

Table 9: Sample Metrics That Relate to Building Energy Efficiency and Resilience

Energy code metric/indicator	Building performance outcome	
	Energy efficiency	**Energy resilience**
Grid peak contribution (kW)	**Reduce consumption**	**Grid resilience**
Demand flexibility (kW)	**Reduce consumption**	**Grid resilience**
Maximum energy load (BTU/ ft^2)	**HVAC sizing**	**Grid resilience**
Wet-bulb temperature (°F)	**Occupant comfort**	**Passive survivability**
Back-up power capacity (kW)	**Renewable Credits**	**Operational resilience**
Envelope air leakage (ACH)	**Reduce heat loss**	**Disaster recovery**
Ventilation requirements (cfm/ ft^2)	**Air quality control**	**Disaster recovery**

The need for additional energy resilience metrics was prioritized through the ORNL workshop described in Section 2.2. As discussed below, more research is needed to establish how to appropriately apply these metrics to measure energy resilience performance and quantify the full range of benefits that would result.

V. Knowledge Gaps and Research Needs

Previous sections of this report have established that building design approaches can be co-optimized to enhance energy efficiency resilience benefits. Building energy codes offer an effective mechanism to set energy resilience requirements that reflect the appropriate hazard risks and operational capacities of buildings. While modern building codes represent an opportunity to enhance building resilience, they do not address all aspects of resilient design, and further study is needed to better understand the relationships between buildings and energy systems. BTO has identified several key gaps, including the need for established and accepted metrics for characterizing energy resilience, a standardized and replicable methodology for quantifying and valuing energy-resilience benefits, and continued technology R&D, such as investigating which energy technologies can better equip buildings to maintain livable conditions, continuity of operations, and minimum levels of functionality under low- and no-power scenarios. Continued progress in these areas can result in a better understanding of how energy efficiency and resilience objectives may complement each other or come into conflict. This understanding can better inform industry model code development, and consensus bodies considering how building codes can contribute to enhanced energy resilience.

The knowledge gaps and research needs identified in the following sections are primarily drawn from the ORNL workshop, as well as ongoing research efforts within BTO and across the buildings industry.

Develop Valuation Methodology

The primary challenge identified was the lack of a standardized methodology for evaluating resilience. Listed below are the specific elements that require further support:

- *Definitions* – An industry-accepted definition of building energy resilience, as well as translation of related sub-definitions (e.g., thermal resilience, operational resilience).

- *Metrics* – An established set of metrics that represent parameters of energy resilience. These metrics should capture the passive survivability of a building from an occupant-based perspective. These include primary metrics, such as indoor air temperatures and humidity levels, as measured over a predetermined period and specified durations and thresholds for backup power systems.

- *Methodology* – A standardized methodology to assess energy resilience and specifically passive survivability. Researchers have relied upon building energy modeling to simulate indoor air temperatures during an outage, but there has been limited work to validate results with real-world data. Building energy modeling tools need to be tested to ensure their ability to simulate a building's performance during an outage.

- *Performance Targets* – Performance targets are needed as a baseline to measure appropriate modeling results. These targets will vary by climate and building type to reflect appropriate standards for sheltering in place. The duration (time) of an outage, the extreme temperature (heatwave or cold front) intensity, and indoor temperatures can serve as parameters for potential standardization. In addition, proposed performance targets should consider both low- and no-power scenarios.

- *Applications* – A robust methodology to evaluate building resilience should be capable of being tested across the entire range of building types and climates, and account for the hazards associated with them. Additional research needs were cited for multi-family buildings because units located on the top floors are particularly susceptible to heat gain.

Characterizing the Relationship Between Energy Efficiency and Resilience

The second challenge identified was the need for a more comprehensive and technical inventory and characterization of energy efficiency measures that complement, conflict, or have no correlation to building resilience strategies. The same energy efficiency measures and resilience strategies cannot be used for all buildings; rather, choices are delimited by the design and performance of buildings under varying conditions.

Energy-resilience benefits are expected to vary due to several key factors, such as climate zone, building type, building characteristics, and occupant behavior. Energy efficiency technologies that complement building resilience may conflict with other objectives in certain instances. For example, increased envelope sealing in cold climates enhances thermal resilience and reduces heating loads but may increase moisture buildup in humid climates due to the lack of air circulation. Additionally, interactions between building occupants and technologies can alter resilience outcomes. For instance, the method used to properly operate a building during periods of poor air quality is a function of available mechanical ventilation, window operability, and occupant behavior.

Additional research is needed to determine optimal approaches to enhance energy resilience. Discussion on how technologies complement and conflict must be based on technical research that confirms and validates evidence. Such work can help identify geographic regions, communities, and building types most susceptible to hazards and energy disruptions. This research can be used by the established industry building code development and consensus bodies in considering updates, which are expected to be particularly impactful for new construction. For existing buildings, retrofit strategies and technology packages can also benefit from further analysis and validation.

Quantify Benefits of Enhanced Energy Resilience

The third challenge identified was the need to quantify the benefits of building energy resilience. The ability to quantify benefits is a natural extension of the initial framework to measure the impacts of enhanced energy resilience, where results are presented numerically (e.g., in dollar amounts or other key outputs). By presenting the benefits of enhanced resilience through a broader cost-benefit framework, results can be utilized by a wider audience.

Quantifying the benefits of enhanced energy resilience derives value from a series of both direct and indirect benefits. Direct benefits primarily include the energy savings a given technology may provide. Indirect benefits reflect the potential risks mitigated through a resilience effort, such as avoided costs of damages and repairs, property damage insurance coverage, as well as health-based outcomes, business interruptions, and equipment damage.

The ability to quantify building resilience is a key component of value-at-risk assessments for building developments, investments, and operations. By quantifying the potential vulnerability of a given building to disaster events and other disruptions, stakeholders can make more informed decisions. A rigorous methodology to quantify building resilience can be used by the insurance sector to incentivize lower risk buildings. Similar to how energy efficiency products are labeled, resilience technologies can also be marketed as providing cost savings. For example, battery storage companies sometimes advertise how their products can contribute to energy system or building resilience.

Integrate Energy-Resilient Design Criteria with Codes and Standard Practice
The growing emphasis on resilience offers an opportunity for the building design and construction industry, building codes, and states and municipalities to integrate energy-resilient design criteria with codes and standards. Model energy codes are already being amended because of considerations related to how building performance affects energy systems. The research priorities described above will provide information about the costs and benefits of energy-resilient design practices, and specific strategies to achieve energy resilience in buildings. Beyond informing sound design practices, this research can also be used by industry code development and standardization bodies, support assessment of evolving practices, and ultimately inform model code updates that would enhance resilience even further.

If states and municipalities desire to fully incorporate enhanced resilience, these entities could consider expanding the scope of energy codes. Historically, the scope and intent of model energy codes have been restricted to setting energy efficiency requirements in buildings. Expanding the scope to include resilience requirements would increase consideration of resilience benefits. In practical terms, economic benefits of resilience could be included in benefit-cost analyses to help justify new codes proposals.

Model energy code updates alone will not fully integrate resilient design and construction practices across the industry. Creating an energy-resilient building stock will require new technologies and practices, which in turn will require awareness and adaptation on by designers, builders, and other industry professionals. Workforce education and training programs will be critical. Education and training programs can help ensure architects, engineers, contractors, building officials, energy raters, and other stakeholders are aware of updates, new practices, and the supporting research and building science. Existing credentialing, licensing, and continuing education programs should create modules addressing resilience. For example, most states requiring industry professionals to complete continuing education units about current state construction codes and standards. Incorporating new resilience provisions and practices would be a logical enhancement of such programs.

Support and Validate Effective Energy-Resilience Implementation
Federal agencies, state and local governments, insurers, and other stakeholders understand that buildings constructed to the latest model codes are more resistant to natural hazards. The increasing costs of post-disaster recovery have spurred national mitigation strategies to encourage building code adoption and implementation processes. According to FEMA, only about half of jurisdictions in areas at risk for disasters have adopted disaster-resistant codes.[144]

Benchmarks and rating systems can be used to assess the resilience of a community's building codes and associated implementation practices. Support for code compliance, including

[144] FEMA, "Building Codes Save: A Nationwide Study," November 2020. https://www.fema.gov/sites/default/files/2020-11/fema_building-codes-save_study.pdf. Accessed November 14, 2023.

education and training programs, is often an underrecognized aspect of building codes that can impact the energy performance, structural integrity, and many other aspects of a building. A range of code tracking and evaluation practices can be readily applied by government-funded and insurance programs to incentivize successful implementation within a given state or community. The means for supporting and validating effective energy resilience strategies via building codes are outlined below.

The International Organization for Standards (ISO) created the Building Code Effectiveness Grading Schedule (BCEGS™).[145] This national program rates communities on a scale of 1 to 10, which indicates jurisdictional commitment—ranging from low to exemplary—to standard code adoption and enforcement practices. ISO worked with the insurance industry to develop the rating system, which considers variables such as the amount of construction activity, enforcement budget allocations, the professional qualifications required of inspectors, and historic code compliance levels. The system helps jurisdictions critically analyze their administration of codes and identify areas for improvement. FEMA applies BCEGS to track the rate of code adoption in the United States, which is equated to improvements in disaster resilience.

Field studies are another critical component of validating the impacts promised by energy codes and other policy instruments. Field studies gather data on technologies and practices as applied in newly constructed buildings, providing valuable insight on the prevalence of certain technologies and construction methods as employed in the field and preferred by market actors. Such studies are a cornerstone of BTO’s technical assistance offerings that support state energy code implementation.[146] Past studies have focused on traditional energy efficiency features such as wall insulation (R value), fenestration (U-factor), air tightness (ACH50), and other energy systems (e.g., HVAC, refrigeration, and lighting). Field observation data is aggregated and can be evaluated against expected conditions, such as those specified in current state building codes, allowing a state to assess how design and construction practices compare in each region. Findings help a state understand whether typical construction practices are, on average, better or worse than expected, and which measure and practices are successful. Findings also identify challenges that can be targeted by workforce education, training, and compliance improvement programs. Findings can also be used to quantify energy, cost, and environmental impacts, enabling a state agency to understand the impacts of their codes and increase the return on investment for ongoing education and training programs by emphasizing the most impactful measures in training modules. As new and advanced technologies enter the market and become commonplace over time—from energy efficiency technologies to onsite generation and energy storage systems—continued field studies offer a

[145] International Organization of Standardization (ISO), *National Building Code Assessment Report: Building Code Effectiveness Grading Schedule* (Jersey City, NJ: ISO), 2019. https://www.isomitigation.com/siteassets/downloads/iso-bcegs-state-report_web.pdf. Accessed November 14, 2023.

[146] DOE EERE Building Energy Codes Program, “Energy Efficiency Field Studies,” https://www.energycodes.gov/energy-efficiency-field-studies. Accessed November 14, 2023.

simple and effective means of tracking the acceptance of new technologies and their impacts on energy resilience.

A concurrent initiative undertaken by the ICC and the Alliance for National & Community Resilience (ANCR)[147] is developing a broad, qualitative framework cities and communities can use to evaluate resilience and undertake specific strategies to increase building resilience. The Community Resilience Benchmarks system (CRBM) assesses a community's ability to deliver essential services across 19 functional areas (e.g., water, energy, solid waste, buildings and communication infrastructure, food distribution, public safety, healthcare, and transportation). The benchmarks are structured around requirements, including actions, plans, and policies that support resilience in each functional area. The system provides information about a community's current level of resilience, the options available to fill gaps, and the benefits of investing in mitigation strategies in advance of hazard events.

Thus far, ANCR has developed pilot benchmarks for Housing and Buildings. The Buildings benchmarks include requirements for: (1) the adoption of building codes; (2) administration and enforcement of building codes; (3) mitigation of highly vulnerable buildings; (4) resilient design; and (5) standards for emergency shelters.[148] Benchmarks related to building codes are contingent upon conducting field study research, like the studies conducted by BTO (as described above). ANCR opened applications in mid-June 2020 for communities to pilot Buildings and Housing Benchmarks, which can help inform the efficacy of the CRBM.

Harden Critical Facilities and Disaster Shelters

State, communities, jurisdictions, and industry partners developing hazard mitigation plans and working to enhance resilience understand that housing residents is one of the most immediate mitigation needs following a natural disaster.[149] Thus, an essential requirement, as specified in ANCR's Buildings Benchmark, is identifying shelter space needs based on the risk of natural hazards facing the community.[150] To support sheltering in place, requirements for buildings and supporting systems include:[151]

1. An acceptable range of thermal comfort (e.g., temperature and humidity levels).

---

[147] The alliance is made up of a diverse group of foundations, private sector, and government partners. See https://www.resilientalliance.org/contributors/.

[148] Alliance for National and Community Resilience, "Community Resilience Benchmarks," https://www.resilientalliance.org/the-benchmarks/. Accessed November 14, 2023.

[149] Alliance for National and Community Resilience, "The Community Resilience Benchmarks," 2019. p.19. https://www.resilientalliance.org/wp-content/uploads/Final-Buildings-Benchmark-January-2020.pdf. Accessed November 14, 2023.

[150] International Code Council, *The Important Role of Energy Codes in Achieving Resilience*, n.d., page 3, https://cdn-web.iccsafe.org/wp-content/uploads/19-18078_GR_ANCR_IECC_Resilience_White_Paper_BRO_Final_midres-ppp.pdf. Accessed November 14, 2023.

[151] Kent Yu, James Newell, Darren Beyer, Chris Poland, Jay Raskin, and Richard Steinbrugge, "Resilient Schools Through Leadership and Community Engagement," from *2016 SEAOC Convention Proceedings*, 2016, https://www.eeri.org/wp-content/uploads/2016_SEAOC_Yu_etal.pdf. Accessed November 14, 2023.

2. The ability to bring fresh air into the building.
3. Lighting (e.g., natural daylight and battery lanterns or flashlights during the evening).
4. A source of water for drinking and personal hygiene.
5. An operating wastewater system or holding tank.
6. Emergency power for lighting, medical devices, recharging personal electronic devices, and critical space conditioning systems.

These and similar benchmarks for critical facilities are expected to evolve as additional needs are identified and tested via the ANCR community pilots. Even the current benchmarks; however, clearly indicate that functional energy systems are crucial to achieving the above goals. BTO and others can continue to support initiatives bolstering community resilience and ensuring continuity of operations in these critical facilities.

VI. Ongoing DOE Work on Energy Resilience

The research needs described in previous sections require a combination of technical research, field validation, and ongoing coordination across multiple researchers, practitioners, and other market and actors to support the advancement of building energy resilience. BTO is actively working in several of these areas through advanced R&D, technical initiatives, and strategic partnerships that support DOE goals of advancing the deployment and application of energy efficient technologies and enhancing the reliability and resilience of the Nation's energy systems.[152]

A summary of current energy-resilience efforts across BTO programs is outlined below.

Each of the BTO programs—Emerging Technologies, Commercial Building Integration, Residential Building Integration, the Appliance and Equipment Standards Program, and the Building Energy Codes Program—support work contributing to building energy resilience. This work includes technology R&D, techno-economic analysis and initiatives addressing technology integration challenges, stakeholder engagement, and other activities that support resilient building practices and a decarbonized building sector. The following sections highlight current BTO programmatic activities, which serve to enhance energy resilience.

Emerging Technologies (ET) Program

ET funds early-stage and applied R&D for building technologies and tools that support building energy efficiency.[153] ET focuses on several specific technology areas, including sensors and controls; dynamic windows and building envelope; building energy modeling; and HVAC, water, heating, and appliances. In addition to technology-focused R&D, ET leads several ongoing

[152] DOE EERE, "Beyond Efficiency: The Benefits of High-Impact Buildings Technologies in the Public Sector," *energy.gov*, June 26, 2020, https://www.energy.gov/eere/articles/beyond-efficiency-benefits-high-impact-buildings-technologies-public-sector. Accessed November 14, 2023.

[153] U.S. Department of Energy, Building Technologies Office, "Buildings: Emerging Technologies," https://www.energy.gov/eere/buildings/emerging-technologies. Accessed November 14, 2023.

initiatives supporting the integration of building energy technologies with the grid. These initiatives focus on technology development, such as smart sensors and controls, that facilitate increased grid resilience by facilitating communication between buildings and grid operators. Other cutting-edge building technologies in development, including dynamic and self-healing envelope solutions, can support passive survivability measures and enable more rapid detection of building maintenance needs prior to a major disruption.

Commercial Buildings Integration (CBI)

CBI collaborates with commercial sector stakeholders to advance deployment and integration of energy efficiency technologies in the commercial market.[154] The program's focus on resilience has been driven by stakeholders who recognize the risks posed to their businesses by hazards and extreme events, as well as climate change. Through the Better Buildings Climate Challenge, CBI has contributed to the development of a Finance and Resilience Roadmap to "help commercial building owners develop a plan for measuring, managing, and mitigating resilience risk."[155,156] The Finance and Resilience Roadmap provides resources that help stakeholders make the financial case for enhanced resilience. The roadmap includes case studies as well as material to support actionable resilience planning.

Residential Buildings Integration (RBI)

RBI is dedicated to the advancement of energy efficient technologies for new and existing residential buildings, and focuses on opportunities to make buildings more affordable, durable, and healthy for its occupants.[157] RBI provides technical assistance to entities including HUD, state energy offices, and local governments seeking to develop mitigation plans, as well as applied research projects pursuing energy resilience. This is achieved through a variety of complementary residential building research and integration programs.

The Building America Program, in particular,[158] is focused on providing actionable, energy efficient applications for residential building construction and renovation. Building America developed the Disaster Resistance Tool,[159] which integrates resiliency and disaster resistant construction into energy efficiency guidance on the Building America website. The construction details were developed by Building America teams in partnership with the Insurance Institute for Business and Home Safety's FORTIFIED Homes program. In addition, DOE's Zero Energy

---

[154] U.S. Department of Energy, Building Technologies Office, "Commercial Buildings Integration," https://www.energy.gov/eere/buildings/commercial-buildings-integration. Accessed November 14, 2023.

[155] U.S. Department of Energy, Better Buildings Solutions Center, "Better Buildings," https://betterbuildingssolutioncenter.energy.gov/. Accessed November 14, 2023.

[156] U.S. Department of Energy, Better Buildings Solution Center, "Finance and Resilience," https://betterbuildingssolutioncenter.energy.gov/finance-resilience-toolkit. Accessed November 14, 2023.

[157] U.S. Department of Energy, Building Technologies Office, "Residential Buildings Integration," https://www.energy.gov/eere/buildings/residential-buildings-integration. Accessed November 14, 2023.

[158] U.S. Department of Energy, Building Technologies Office, *Building America Solution Center* https://basc.pnnl.gov/. Accessed November 14, 2023.

[159] U.S. Department of Energy, Building Technologies Office, *Disaster Resistance*, https://basc.pnnl.gov/disaster-resistance. Accessed November 14, 2023.

Ready Homes program, which is focused on energy efficient construction recommends builders increase durability of residential buildings with the FORTIFIED Homes checklists.

Grid-interactive Efficient Buildings (GEB) Initiative

The ET Program plays an important part in BTO's Grid-interactive Efficient Building (GEB) Initiative, which seeks to advance the role buildings can play in support of a resilient grid.[160] The GEB strategy includes dynamically managing building energy end uses to help meet grid needs and minimize electricity costs while meeting occupant requirements for comfort and productivity. BTO is investing in technologies and research that support energy efficient buildings equipped with smart sensors, controls, equipment, and energy storage that respond to utility price signals and optimize energy use.

The GEB initiative also tests functionality in "real world" scenarios through competitive funding opportunities. The "Smart Neighborhoods" and "Connective Communities" pilot projects brought together successful partnerships between DOE, electric utilities, and real estate developers. Additional information can be found online for the new Connected Communities.

Energy-Resilience Valuation

BTO initiated a research project aimed at better understanding and quantifying the value streams that building efficiency and demand flexibility provide to energy resilience. This 18-month project began in 2020 with the intent of developing a standardized methodology for quantifying the value of energy resilience to support sheltering in place in the face of extreme temperature events. The project contributors include researchers from three DOE research labs, namely the Pacific Northwest National Laboratory (PNNL), Lawrence Berkeley National Laboratory (LBNL), and the National Renewable Energy Laboratory (NREL), as well as a group of industry experts in a technical advisory role. The approach will account for the risk and vulnerability of prototypical buildings and those improved with mitigation measures, and by hazard risk across several U.S. regions. The building vulnerability will be based on existing building conditions, including current and above-code measures, as well as metrics indicating vulnerability, which will be assessed using building simulation analysis. In addition to the standardized methodology for valuing resilience, the project will also evaluate current resilience definitions, metrics, and challenges[161], as well as a path for better integrating resilience with relevant industry standards.

Other Collaborations Across DOE and Building Industry Sector

BTO is actively involved in several ongoing collaborations with entities across the Office of Energy Efficiency and Renewable Energy (EERE), the broader Department, and the White House and other government agencies. Highlighted below is a summary of two notable collaborations:

[160] U.S. Department of Energy, Building Technologies Office, "Grid-Interactive Efficient Buildings," https://www.energy.gov/eere/buildings/grid-interactive-efficient-buildings. Accessed November 14, 2023.

[161] Such as those identified via the ORNL Energy-Resilience Workshop.

- **National Initiative to Advance Building Codes (NIABC):** The White House National Climate Task Force launched this cross-agency initiative to modernize building codes, improve climate resilience, reduce energy costs, prioritize underserved communities, and create good-paying jobs.[162] Participating agencies include FEMA, DOE, EPA, GSA, HUD, USDA, NIST, and others.

- **DOE Resilience Community of Practice (COP):** The Resilience COP brings together offices within EERE, as well as the Office of Electricity. Members can provide updates on relevant projects, share resources and knowledge, and stay informed on efforts across DOE and the Federal Government. Members also coordinates on various activities, such as providing technical feedback for the recent public notice on FEMA's Building Resilience Infrastructure and Communities Program.

- **The Education Materials for Professional Organizations Working on Efficiency and Renewable Energy Developments (EMPOWERED) funding opportunity:** In collaboration with the Vehicle and Solar Technologies Office, BTO selected a funding opportunity for projects to develop training resources for professionals interacting with emerging energy technologies.[163] One EMPOWERED topic is dedicated to projects that support disaster response and resilience planning.

- **The Building Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) funding opportunity:** BTO has funded for multiple years projects to research and develop innovative technologies "that will improve energy productivity, improve flexibility, security and resiliency, as well as lower energy costs of our Nation's buildings and electric grid."[164] Of the projects funded in 2020, two focus on adaptive building controls that increase the resilience of building energy systems.

- **The Advanced Building Construction (ABC) initiative:** ABC advances "the integration of energy efficiency solutions into highly productive U.S. construction practices for new

---

[162] Office of the President of the United States, "FACT SHEET: Biden-Harris Administration Launches Initiative to Modernize Building Codes, Improve Climate Resilience, and Reduce Energy Costs," https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/01/fact-sheet-biden-harris-administration-launches-initiative-to-modernize-building-codes-improve-climate-resilience-and-reduce-energy-costs/. Accessed November 14, 2023.

[163] U.S. Department of Energy, Building Technologies Office, "Funding Opportunity Announcement: Education Materials for Professional Organizations Working on Efficiency and Renewable Energy Developments (EMPOWERED)," https://www.energy.gov/eere/solar/funding-opportunity-announcement-education-materials-professional-organizations-working. Accessed November 14, 2023.

[164] U.S. Department of Energy, Building Technologies Office, "Department of Energy Announces up to $47.7 Million for Flexible Building Technologies, Heating, Ventilation and Air Conditioning (HVAC), and Solid-State Lighting," https://www.energy.gov/eere/buildings/articles/department-energy-announces-477-million-flexible-building-technologies. Accessed November 14, 2023.

buildings and retrofits."[165] Among the projects the ABC fund, several investigate materials and construction practices that increase resilience and disaster recovery efforts.

VII. Conclusion

Resilient buildings strengthen the mitigation of, response to, and recovery from unforeseen and adverse events, from extreme weather events to pandemics and their cascading impacts. Buildings are a form of infrastructure serving as a place of shelter, workplace, and critical services, sustained through building energy systems and connections to the bulk power system.

The value of building resilience is increasingly evident as the Nation, states, and communities plan and prepare for hurricanes, heatwaves, wildfires, and amid the ongoing effects of the COVID-19 pandemic. The pandemic significantly shaped disaster response protocol and critical facility designations so that, as disaster shelters and evacuation procedures account for pathogen transmission risk. For example, FEMA issued special operational guidance for the 2020 hurricane season to allow for the use of non-congregate shelters, including hotels, motels, and dormitories.[166] Researchers have also expressed concern about how pandemics impact cities during heatwaves.[167] As buildings are implicated in both the spread and reduction of infections, building energy technologies are being called upon to play an active role in reducing transmission risks and supporting shifting uses of building space.

Energy efficiency technologies and practices can contribute to the resilience of buildings and supporting infrastructure during each stage of a disaster event. Energy resilient buildings can better absorb the effects of wind, rain, extreme temperatures, or other forces, and protecting people. Developed through industry consensus processes, model building codes are updated to account for the variety of hazards across multiple climates and geographies. States and localities then assume the responsibility of adopting these codes and ensuring compliance with the latest requirements, which can provide a further opportunity to adapt these standards to the risks faced by at the regional and localized levels. Building energy codes offer an established policy mechanism that incorporate modern technologies, evolving risks, and the key features of buildings impacting building energy resilience.

The latest building codes are widely considered a cornerstone of resilient design practices. Currently, energy codes can enhance the resilience of new buildings through increased energy

---

[165] U.S. Department of Energy, Building Technologies Office, "Advanced Building Construction Initiative," https://www.energy.gov/eere/buildings/advanced-building-construction-initiative. Accessed November 14, 2023.
[166] Federal Emergency Management Agency, COVID-19 Pandemic Operational Guidance for the 2020 Hurricane Season, https://www.fema.gov/media-collection/covid-19-pandemic-operational-guidance-2020-hurricane-season. Accessed November 14, 2023.
[167] Stephan Bose-O'Reilly, Hein Daanen, et. al., "COVID-19 and heat waves: New challenges for healthcare systems," Environmental Research, Volume 198, July 2021, 111153. https://doi.org/10.1016/j.envres.2021.111153. Accessed April 11, 2022.

efficiency and by establishing minimum standards for building energy technologies. In the future, building codes, including energy codes, will likely incorporate additional resilience measures, as proven technologies and practices become available in the market. There is also an emerging emphasis on new metrics that can measure or value the resilience characteristics of a building or specific design measures. Metrics that prioritize continuity of operations and livable indoor environments to better enable occupants to shelter in place following an event will be important.

BTO has identified several knowledge gaps and prevailing challenges that require additional study. Accepted methods for quantifying the value of energy resilience are needed to enable decisions around individual building technologies and mitigation-oriented design strategies. Continued R&D can further support the co-optimization of energy efficiency and resilience benefits, address integration challenges confronting building systems and their interconnectivity with the utility grid, and support commercialization of new and advanced technologies. BTO, in partnership with the National Labs, is equipped to partner with industry and conduct further research based on these recommendations and can support efforts to enhance the resilience of buildings and energy systems as the industry advances technologies, practices, and supporting methods.