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Workshop on the Nexus of Resilience and Energy Efficiency in Buildings: Proceedings Report

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September 30, 2019

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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EXECUTIVE SUMMARY

Nexus of Efficiency and Resilience

For both new and existing buildings, energy efficiency and resilience have become imperatives that must be fully integrated for truly sustainable buildings. Efficiency and resilience measures have typically been condidered individually despite significant overlap in effects, sometimes to their mutual benefit, sometimes at odds. The effectiveness of efficiency and resilience technologies depends on their context (e.g, building charteristics and operations, climate region, or specific hazards). Effective integration of efficiency and reslience requires a baseline understanding of the nexus of efficiency and resilience measures in the following categories:

- efficiency measures that complement resilience
- efficiency measures that conflict with resilience
- resilience measures that provide critical value and should be added to efficient buildings

Workshop participants explored this nexus of efficiency and resilience separately for building enclosures and operations.

Challenges and Opportunities

Efforts to integrate eficiency and resilience must address critical challenges and leverage the most significant opportunities including the following:

Enclosures		Operations	
Challenges	**Opportunities**	**Challenges**	**Opportunities**
Lack of planning and priorities	Improved, clear rating systems	Knowledge & awareness gaps	Greater knowledge & awareness
Lack of policies	Codes	Insufficient resilience modeling	New financing & incentives
Uncertain cost/benefits	Defined value proposition / business case	High or uncertain costs	Technology R&D
Siloes	Greater collaboration	Lack of collaboration	Greater collaboration
Lack of education & awareness	Greater education & awareness	Uncertain resilience valuation measurement	Defined resilience valuation
Power grid integration	Studies and tools	Building complexity & design	Advanced structures & modular designs
Knowledge/research gaps	Pilot projects	Energy “routing”	Smart systems
	Workforce training		Codes & standards
	Advanced structure & components		“Low tech” guidance

High-Priority Actions

Based on the challenges and opportunities, potential high-priority quick-win and game-channging actions were identified and action plans were prepared. These actions include the following:

Enclosure Actions	Operation Actions
• Review adoption/modification above-code programs • Advancing codes to address resilience holistically • Tools and analyses for the nexus of efficiency, load flexibility & resilience • Public facing education & awareness • Resilience rating system • Develop resilience value proposition	• Icentivize This! Insurance & underwriter resilience incentives • Create an energy efficiency & resilience (EER) utility • Methodology to optimize resilience & efficiency value • Advanced energy efficiency & resilience design guides • Create reslience benchmarking for zoning/bldg. codes • Up the PACE—Integrate resilience in PACE financing • Cost-effective ‘DIY’ packages and solutions

	• Grid-friendly, resilient, eff. HVAC, DHW, air distribution • Actionable resilience information for businesses

Next Steps
Based on content from the workshop and in coordination with other stakeholders, may develop a plan for effectively integrating resilience into current programs delivering energy efficiency improvements.

CONTENTS

INTRODUCTION

There is an array of building technologies whose operation—either passively or actively—holds the potential to improve resilience for building occupants and owners, utilities, communities, and other financial interests. Recent decades have witnessed enhanced resilience to major disruptions, as well as significant improvements in the energy efficiency of building technologies. However, these dual goals have often been pursued independently of each other. Similar levels of energy efficiency can be realized by a range of different technologies. For example, buildings can be kept cool in summer through passive ventilation, more efficient heating, ventilation, and air conditioning (HVAC), higher quality walls and windows, advanced control systems, and intelligent analytics enabled by IoT technology. However, each of these technologies realizes energy efficiency through a different mechanism, and those mechanisms may contribute to resilience in non-uniform ways. One purpose of this workshop was the identification of specific energy efficiency and load flexibility characteristics, followed by an assessment of how those characteristics map onto the resilience space.

In June 2019, Oak Ridge National Laboratory hosted a two-day workshop to explore how and where the two areas overlap, complement, or interfere with each other. A diverse group of experts assembled to discuss how to mutually address goals for improving the efficiency and resilience of our nation's buildings. While this workshop only considered energy efficiency and load flexibility technologies that were realized through behind-the-meter technologies, all forms of resilience were considered. That is, the impact of these technologies on building occupants, building owners, business operators, utilities, communities, and all other relevant stakeholders were within scope.

The workshop began with a plenary session to provide context for the breakout sessions that followed. Plenary presentations reviewed existing perspectives and practices on energy efficiency, resilience, and the intersection between the two, noting both opportunities and challenges. Speakers also discussed successes with integrating resilience into buildings.

Following the plenary were four facilitated discussions, or breakout sessions, designed to look more deeply into specific topics. The first session identified examples of efficient, flexible, and resilient technologies and systems. In the second session, participants explored the nexus between energy efficiency and resilience technologies and practices (i.e., where the two can be mutually beneficial and where they potentially conflict) to better understand the trade-offs and interplay between these dual goals. Informed by these trade-offs, participants in the third session identified challenges and opportunities to integrate energy efficiency and resilience in building-related research and development (R&D), policies, programs, or other avenues. Participants down-selected the list of opportunities, considering both priority opportunities to implement quickly at low cost (quick wins) and opportunities that would have high impacts in the long term (game changers). During each session, two topics were considered separately: building enclosures (e.g., roofs, walls, windows, and foundations) and building operations (e.g., HVAC, efficient components, indoor air quality, renewable generation, and grid-interactive buildings). The first day ended with reporting from all the breakout sessions.

The fourth breakout session began on the second day. Each group developed a preliminary action plan to pursue a selected opportunity that would better integrate energy efficiency into both pre-disaster mitigation and post-disaster recovery activities. As on the first day, the groups reported their results to the larger group, and participants collaborated to identify next steps.

This report summarizes the proceedings, discussions, and results of the workshop. For reference, a copy of the agenda is included as Appendix A, and a list of participants, by breakout group, is included in Appendix B.

1. PLENARY SESSION & LUNCH PANEL

1.1 EFFICIENCY, FLEXIBILITY, AND RESILIENCE—CONNECTIONS AND OPPORTUNITIES

Dr. Karma Sawyer – Program Manager, Building Technologies Office, U.S. Department of Energy

Dr. Karma Sawyer discussed the U.S. Department of Energy's (DOE's) Buildings Technologies Office (BTO) perspective on the nexus between efficiency and resilience in buildings. BTO supports technologies and practices that apply to more than 123 million residential and commercial buildings in the United States, which represents the largest single energy end-use sector. More than 80% of this building stock is more than 20 years old. Research supported by DOE has led to energy-saving improvements in building materials and appliances, but further research is needed to delineate how and when efficiency can work to improve resilience for pre- and post-disaster use cases.

Resilience is the ability to predict, prepare for, withstand, recover rapidly from, and adapt to major disruptions. A resilient building will recover from an event more quickly than a traditional building. BTO believes that high-performance buildings can deliver resilience value streams, for example, by reducing insurance premiums before a disaster (e.g., using the FORTIFIED™ home designation) and potentially avoiding the heavy financial burden associated with outages post-disaster. Moreover, incorporating resilience into a high-performance building helps to protect the investment of taxpayer dollars over the lifetime of the building. Most importantly, resilient buildings contribute to public health and safety, especially in the event of a natural disaster.

Building codes are a familiar policy instrument that can be leveraged to increase resilience. Building codes address a range of energy and resilience issues in the built environment, establishing minimum levels of performance in every state. Local governments typically enforce building codes and may tailor requirements to their specific regional concerns.

The Stafford Act lays out a system for the federal government to work with state and local governments to mitigate hazards associated with natural disasters. Provisions of the Stafford Act, amended by the recent Disaster Recovery Reform Act (DRRA), reserve significant funding (potentially billions of dollars) for pre-disaster resilience improvements to mitigate hazards. This funding could be game changing for state, local, territorial, and tribal governments to invest in resilience. Best practices for co-optimizing efficiency and resilience that demonstrate the added value that energy efficiency measures provide are needed to make best use of this funding.

BTO has two major building efficiency initiatives: Grid-Interactive Efficient Buildings (GEB) and Advanced Building Construction with Energy-Efficient Technologies & Practices (ABC). GEB employs a holistic approach, reaching beyond the building to make it efficient, connected, flexible, and smart. A pilot project to develop a smart neighborhood in Alabama demonstrates some of GEB's potential for efficiency, and the project has also incorporated resilience improvements (e.g., the community can be islanded from the broader distribution grid via microgrid). This project is an example of efficiency and resilience working in tandem.

ABC is an early-stage R&D program seeking deep energy savings from transformational technologies that can be tailored for regional savings. This program includes efforts targeting thermal loads—space heating, space cooling, water heating, and ventilation—which creates overlap with resilience performance. This program also seeks to rapidly increase the pace of building envelope retrofits, which requires an understanding of resilience implications of efficiency choices made during the retrofit.

There are many recent concrete examples of advancements made through these programs that could improve both efficiency and resilience:

- During a polar vortex in 2019, utilities in the Midwest asked customers to turn down thermostats to reduce fuel use; GEB could aid in managing this energy demand.

- High R-value insulation improves energy efficiency but has no specific resilience benefits. Many modern materials and technologies that promote energy efficiency also have wide-ranging performance in fire resistance.

- Hurricane Irma hit Florida in 2017, causing damage and outages. One nursing home lost its main air conditioning system, contributing to the deaths of 12 residents. Most passive energy efficiency measures modeled after this tragic incident would have been effective at making the building more resilient. However, one of the efficiency measures considered—reducing infiltration—performed worse than the baseline. Finally, modeling demonstrated that the effects of efficiency measures on building performance in indoor temperature and humidity are location-specific. Modeling the same efficiency measures in the same building but subject to a heat wave in San Francisco, California, resulted in similar, though not identical recommendations for improving resilience.

The nexus between efficiency and resilience is complicated because, while there are opportunities where they align, pitfalls also exist where each goal is at odds. BTO and the communities pushing for improvements in both efficiency and resilience must be careful and thoughtful on paths forward. Different building types, different climate zones, and many other factors can affect the interplay between these two essential building characteristics.

1.2 RESILIENCE IN PRACTICE

Laurie Schoemann, Senior National Program Director, Resilience and Disaster Recovery, Enterprise Community Partners

Enterprise Community Partners is an organization dedicated to ensuring national affordable housing by building new affordable housing and protecting existing housing. The not-for-profit has 11 offices around the country that prioritize the most important issues in their regions, including homelessness and displacement, economic disparity, equity, and a lack of affordable housing. Enterprise Community Partners also runs disaster recovery work.

In the past three years, natural disasters caused more than $290 billion in damages. While the costs to repair physical damage are high, the costs to communities are often higher. The loss of electricity and water can lead to illness and death. Unfortunately, modeling based on experience may not be sufficient to assess future risk to communities.

In the aftermath of a disaster, many communities recognize the opportunity to rebuild better and more resilient, with support from federal funds to aid the recovery. However, these communities need evidence-based solutions that can help them direct funding strategically to create communities that are better than they were before the event.

Recovery takes a long time and may be complicated. Resources dedicated to resilience help protect taxpayer investment in infrastructure and housing and sustains services and local economies. Resilience must account for more than a cost–benefit analysis of avoided physical damages. Evaluating community resilience requires looking holistically at the people, physical assets, operations, revenue streams, and reputation of the community, which may all suffer in the aftermath.

When Superstorm Sandy impacted New York City, the city faced a number of questions common to communities that receive federal support to recover from a natural disaster: What projects are highest priority? Who are the stakeholders? How should programs be structured, and what staff requirements are there?

In response to Sandy, Enterprise Community Partners created programs in New York City and developed a Ready to Respond tool kit and strategies for multifamily housing resilience. The organization provided owners with a list of strategies as well as strong visuals, case studies, and other materials to communicate best practices in resilient design, operations, and maintenance. While funding for some technical assistance came from the federal Community Development Block Grant Disaster Recovery Program, energy rebates and incentives can be another source of funding for some resilience measures.

In Puerto Rico, Hurricane Maria crippled sewer systems and energy distribution systems, especially the electric grid. Portions of these systems remain offline today. More than 50% of the population lives in self-built housing, often not built to code and unlikely to withstand a significant natural hazard event. Enterprise Community Partners traveled to Puerto Rico to assess the results of the hurricane. The organization sought to determine how best to ensure future housing is built to withstand extreme events and that low-income households may thrive even in the face of increasing natural disasters. Enterprise Community Partners developed a guide with strategies similar to those published after Superstorm Sandy but specific to Puerto Rico, as well as a guide for resilient housing design in island communities.

Based on the experience from these events, Enterprise Community Partners defined a process to build resilience in a community: diagnose, strategize, implement, manage, monitor, and improve.

Future opportunities to collaborate to foster resilience include developing a housing resilience standard, defining co-benefits, and investing. Both private and federal funding is needed to implement resilience.

1.3 ANECDOTES OF SUCCESS INTEGRATING RESILIENCE IN BUILDINGS AS A PART OF PLANNING, CONSTRUCTION, AND POST-EVENT REBUILD

Nikhil Nadkarni, Cambridge Community Development
Michael Walton, Greenspaces Chattanooga
Jeremy Williams, Building Technologies Office, U.S. Department of Energy

Nikhil Nadkami: Cambridge is developing a preparedness plan that will focus on key neighborhoods facing flooding, heat island effects, and poverty. The Cambridge Community Development organization worked with the community to identify three major components: investment in green infrastructure (to reduce the impact of flooding) and energy resilience, social networks to help the community rebuild (so people know who to contact for assistance) and participate in planning, and superblocks for community microgrids.

Michael Walton: Greenspaces Chattanooga historically focused on building technical assistance but has shifted more toward community resilience in the last five years. Current efforts have been informed by community needs that appear, for example, in calls to the utility support hotline. Ongoing work includes building social infrastructure and conducting deep energy retrofits. The work is focused on the built environment, seeking to reduce energy use through education and retrofits. Building social infrastructure through community engagement is important because vulnerable communities with social infrastructure fare better in disasters.

Jeremy Williams: In a way, resilience is not new to codes. Fire, wind, moisture, and other codes all improve resilience, but codes often leave out energy efficiency. There is a newer focus on codes for retrofit projects, as well as on updating codes in a way that allows for more direct response toward resilience. Codes can be envisaged as "standard of care" rather than through a regulatory mindset.

2. BREAKOUT SESSION 1: EXAMPLES OF EFFICIENT, FLEXIBLE, AND RESILIENT TECHNOLOGIES AND SYSTEMS

Participants were asked to think of one example of a flexible or energy efficient building technology or system whose operation can make it easier for occupants, owners, utilities, communities, or any other group to withstand or rapidly recover from a major disruption. This brainstorming exercise was an opportunity to bring forth top-of-mind ideas and concerns specific to energy efficiency or resilience that support improved resilience in particular.

2.1 ENCLOSURE

The enclosure group identified a range of example building technologies and best practices, both existing and potential, that could enhance resilience throughout the building envelope and at the interface with operations.

Materials can support resilience. Building envelopes may be designed and use materials to enable fast drying after flood events, without compromising energy efficiency or comfort. Cool reflective paint on the envelope roof and walls can help to manage temperature fluctuations. Structurally, insulating concrete forms (ICF) offer multiple advantages over wood frame construction for resilience to weather, fire, and earthquake risks while also providing energy efficiency improvements. Highly insulating dynamic windows—for example, made with thin triple glazing or vacuum-insulated glazing—provide improved thermal performance in severe cold and heat.

Building design can make it easier for occupants to withstand or recover from a major disruption. Green or blue roofs address high rainfall storm events. Attics can incorporate ventilation, insulation, and radiant barriers to lower peak load. The ratio of window surfaces to wall surfaces should reflect the local risk (e.g., to projectile impacts or insulation needs). Operable windows and shutters are important for controlling ventilation and airflow during a power outage. Passive designs that incorporate natural heating, cooling, and lighting could improve habitability in the event of a power outage. In areas prone to tornadoes, internal safe rooms and multipurpose shelters can be designed and built into structures.

Renewable energy sources and energy storage can be built into the envelope. Solar photovoltaics (PV) is frequently added on the roof, but new technologies could support incorporating solar PV further into building design and components (e.g., solar shingles). While batteries/electric storage complement solar PV built into the envelope, thermal storage can be integrated into the enclosure to help maintain habitability after an event.

Controls may improve resilience of structures while adding to energy efficiency. For example, flexible or tunable ventilation could optimize the connection between indoors and outdoors to take advantage of favorable conditions. Demand response helps to curtail load during an event and prevents further loss of generation. Back-up power specifically for essential control and communication systems would support continued operations.

2.2 OPERATIONS

The operations group discussed a broad range of fitting examples, and several categories emerged from the discussion: distributed energy resources (DERs); design; construction materials, equipment, and processes; and sensing, analytics, and controls.

DERs included onsite renewable energy generation as well as traditional technologies such as gas or diesel generators and newer systems such as combined heat and power (CHP). More future-looking ideas included distributed low-energy wastewater treatment systems that can both treat wastewater and produce fuels for small-scale power generation. There was also a focus on providing energy when needed during or after a disaster, as buildings' critical operations must be supported. Options for delivering this energy included portable batteries, quick-connect solar panels, and district energy "ports" for mobile boilers and chillers. Community solar could support medical equipment, refrigeration, and communications equipment. Onsite renewables generally could service critical loads if the right inverter is available; this option would likely work in connection with battery back-up power.

Participants discussed various aspects of building design related to resilience. Passive designs and high-quality insulation can mitigate temperature fluctuations. Advanced building construction could include improved designs that enable rapid recovery and incorporate modular water and power supply. Modular permanent housing is an example of advanced construction that allows for innovative efficiency and resilience approaches.

Construction materials, equipment, and processes have great potential to improve building efficiency and resilience. Cross-laminated timber structures provide projectile resilience, blast performance, and thermal mass. Storm-proof windows and shutters similarly withstand projectiles and, paired with insulation, could improve energy efficiency.

Sensing, analytics, and controls comprised its own category. Sensing elements could alert residents or building operators to degraded indoor air quality, whether caused by wildfire or air pollution, and various controls could extend habitability in affected buildings (e.g., closing windows or activating filters). Controls could also support community resilience by rationing power during an event; certain operating modes would reduce functionality for non-vital systems, thereby reserving sufficient power for critical operations. Microgrid load controllers could automatically identify available power resources and operate control schemes to service critical loads.

Integrating HVAC with energy storage, DERs, and advanced controls and sensors would provide many resilience functions. For example, advanced sensors could notify occupants about gas leaks or moisture infiltration.

2.3 RESILIENCE RISK FACTORS

Resilience risk factors that should be of concern before, during, and after an event were identified prior to the workshop and divided into four categories:

- Building Structure Risk Factors
- Building Operations Risk Factors
- Continuity of Business Operations Risk Factors
- Community/Systemic Risk Factors

A combined, updated list of resilience risk factors, informed by feedback from both breakout groups, is presented in the inset below. Relative weight for the resilience risk factors is not considered. Furthermore, these factors are not independent; for example, failures of structural elements impede operations. Nonetheless, metrics or an assessment of potential vulnerability, likelihood, and consequence for each risk would help to prioritize further consideration of these risk factors.

Updated Resilience Risk Factors

Building Structure Risk Factors

- Projectile impact resistance
- Wind load resistance
- Structural lateral force resistance
- Structural dead load resistance
- Ice dam resistance
- Adequate height above grade
- Fire resistance
- Pest resistance
- Water-resistant structure
- Bulk moisture resistance
- Erosion resistance
- Pressure differential resistance
- Chemical and radiation resistance
- Recovery of building infrastructure following an adverse event

Building Operations Risk Factors

- Appliance and/or equipment failure
- Lack of knowledge of human behavior, human tolerance issues
- Loss of power/fuel source (electricity, natural gas, solar, storage, etc.)
- Lack of lighting
- Inability to pump water to high floors
- Compromised ventilation/reduced air quality including from occupant activity (e.g., lighting fires, improper generator use, grills)
- Thermal survivability (e.g., shelter in place) during extreme heat/cold events
- Lack of containment of hazardous materials
- Compromised building management systems or other digital controls (e.g., due to cyberattack)
- Device interoperability or repurposing

Continuity of Business Operations Risk Factors

- Maintenance costs for pre-disaster mitigations
- Softer fails and restarts of mechanical equipment
- Loss of revenue and other business-interruption costs to businesses whose property is compromised
- Inability for businesses to provide critical services
- Compromised waste collection, sewage disposal, or other sanitation issues
- Inability for emergency shelters, schools, fire stations, hospitals, or other facilities to provide critical services
- Food/medicine spoilage
- Medical equipment outages
- Loss of commercial inventory if goods processing is time-sensitive
- Impact on community/business reputation

Community/Systemic Risk Factors

- Access to information
- Anxiety, stress, trauma, and PTSD
- Inability for grid to provide reliable power
- Costs associated with grid black starts
- Costs for urban search and rescue
- Economic losses within the broader community
- Lack of community cohesion before, during, or after an event
- Population displacement (e.g., through gentrification) resulting from pre-disaster mitigation
- Permanent population losses within the broader community post-disaster
- High energy burden
- Security

3. BREAKOUT SESSION 2: UNDERSTANDING NEXUS BETWEEN BUILDINGS ENERGY EFFICIENCY AND RESILIENCE

During this breakout session, participants explored the nexus and interplay between energy efficiency or load flexibility technologies and practices and resilience technologies and practices. This discussion occurred in two phases. First, energy efficiency and load flexibility technologies and practices either *complement* or *conflict* with each other were identified. This approach improved understanding of how these two goals can align or misalign. Second, resilience technologies and practices in buildings without clear impact on or intersection with energy efficiency or load flexibility were identified. This discussion of *currently uncorrelated* technologies and practices added clarity to scenarios in which energy efficiency technologies may need to work with or around resilience requirements. Participants were asked to answer the following questions:

- How do energy efficient/load flexibility technologies and practices in buildings positively or negatively affect resilience?
- What resilience technologies and best practices in buildings are necessary to address resilience risk factors but are currently uncorrelated to energy efficiency or load flexibility?

The summary of these discussions has been sorted below into a collection of building technology categories. Complements, conflicts, and non-correlated characteristics are considered holistically within each category.

3.1 ENCLOSURES

In the building enclosure, efficiency and resilience practices in **attics** may *complement* or *conflict*, depending on the hazard. For example, unvented attics improve resilience to wildfire and wind hazards but not to severe winter weather. Unvented attics may or may not affect efficiency depending on other building characteristics. For example, unvented attics likely improve efficiency with HVAC systems and ducts in the attics. Vented attics, on the other hand, can improve efficiency in hot summer months and improve resilience to moisture damage in cold winter months. Vented attics less resilient than unvented attics to wildfire and high winds.

The **envelope insulation and infiltration** similarly demonstrate areas where resilience and efficiency may be in *conflict* or *complement*. High R-value insulation mitigates risks associated with thermal survivability while enhancing efficiency in normal circumstances. A tight air seal helps to maintain indoor temperatures in cold climates, improving both efficiency and resilience. Efficiency technologies and practices may conflict with resilience goals where increased sealing of the envelope increases the risk of moisture build-up, or where low air infiltration leads to unhealthy indoor temperatures that could result from a power outage during a heat wave.

Windows represent a key area for innovative technologies to improve energy efficiency, but there are clear trade-offs with resilience. Some efficiency technologies and practices *complement* resilience. Low window-to-wall ratio reduces vulnerability to projectile impacts, increasing wind resistance, while also improving thermal insulation for efficiency. Anti-shatter window films similarly mitigate wind-related risks while reducing heat gain. Other technologies and practices *conflict* with resilience goals. Large, openable windows could be vulnerable to smoke intrusion from wildfires and to wind and water intrusion and wind-borne projectiles during intense storms. Modern windows and cladding can provide excellent insulation but may not be sufficiently resistant to fire. R&D for windows technology to improve resilience or efficiency could proceed independently. For example, impact-rated/impact-resistant windows are *currently uncorrelated* with efficiency measures, but efficiency should be considered in future efforts to ensure development toward both goals.

Structural and framing elements, along with the **construction and installation practices** to deploy them have trade-offs between resilience and efficiency in the building envelope. On the *complementary* side, strong insulating materials provide impact resistance and improve efficiency. Construction techniques like insulated concrete forms or panels (ICF and ICP) can provide efficient insulation as well as improved wind, fire, flood, impact, and pest resistance. On the other hand, some advanced wall framing techniques for efficiency could *conflict* with resilience, increasing vulnerability to fire, flood, impact, and pest hazards. There are also materials and construction techniques to improve resilience that are currently uncorrelated with efficiency. Building materials with low global warming potential help to mitigate hazard threats generally but may not have any effect on efficiency. Off-site construction allows for rapid recovery after an event, but efficiency may or may not have been a consideration in the design. Steel fasteners for exterior insulation may perform well to protect the envelope during a disaster, but they may act as a conduit for heat, taking away from energy efficiency

Many enclosure-related resilience technologies and practices mitigate risks from specific **natural hazards** and are *currently uncorrelated* with energy efficiency. Earthquake resistant construction in earthquake zones and seismic reinforcements may represent untapped opportunities to simultaneously improve efficiency. Stormwater management practices incorporated into the structure and landscape—raised homes, sponge landscaping, blue/green roofs, permeable pavement—improve resilience but could be considered as an avenue to lower heat island effects. Fire resistant materials, sprinkler systems, spark arrestors in outside air filters are typical in fire prone areas but could be aligned with energy efficiency goals. High wind hazards prompt safe rooms and tornado shelters, hardened exteriors for impact resistance, storm shutters, and wind resistant roofing; these technologies and practices should be considered in designing energy efficiency measures.

3.2 OPERATIONS

Intelligent functionality and controls in buildings operations offer many advantages for energy efficiency, but likely pose many advantages and disadvantages when considering impacts to resilience. As a point of *conflict*, greater reliance on electricity, which can improve the efficiency of many processes, increases vulnerability to power outages without sufficient back-up solutions. For example, onsite water filtration systems may add to resilience, but fail to operate without power. Grid connected solar PV and other DERs may not provide local back-up power depending on the interconnection agreement with the utility. Integrating powered systems through smart home devices and home automation can deliver operational efficiency but can exacerbate resilience concerns without power for required communications. These devices may support grid efficiency and resilience during normal operations by providing data or demand response capabilities, but without power, IoT devices could hinder the ability to restart. Grid interactive buildings, enabled by IoT, represent one point where technology related to loss of functionality may *complement* efficiency and resilience: such devices could enable local islanding and address concerns about using DERs generation. Improving the resilience of the smart controls could thereby improve resilience of all building operations supported by those controls. On a broader scale, intelligent devices can improve grid resilience at the utility scale, intelligently interrupting power to protect critical facilities. Several resilience factors can address loss of functionality but are *currently uncorrelated* with efficiency. These include plans and exercises for energy assurance and continuity of operations. Cybersecurity is another issue that will need to be addressed for resilience, but its impact on efficiency is not well understood.

Onsite generation with **distributed energy resources** is generally seen as *complementary* for both resilience and efficiency. DERs include solar PV, CHP, standalone generators, and solar heat collectors, and with the right installation and interconnection, DERs can provide power in the event of a wider grid outage. DERs may offer further benefits to both efficiency and resilience by providing DC power directly to appliances that can use it. Natural gas technologies can help resilience and energy efficiency for heating applications, as well as through CHP installations. At a high level, the direct global warming potential and the carbon content of natural gas contribute to climate change, however, which c*onflicts* with resilience goals.

Both electric and thermal **onsite energy storage** similarly *complements* efficiency and resilience. Transportable battery storage, whether electric vehicles or specially designed units, can be moved to safety ahead of a natural hazard given sufficient warning, or may be deployed as emergency power after an event. Increased insulation on operational equipment can improve efficiency and potentially provide benefits for habitability. However, certain types of thermal energy storage, for example in hot water heaters or ice in refrigerated storage, may represent a point of *conflict* as efficiency is achieved by minimizing heating or cooling requirements, but more energy is stored and available if needed by maintaining higher or lower temperatures respectively. Energy storage with Li-ion batteries may have potential efficiency gains, but Li-ion's flammability and potential to explode creates a significant new concern.

Building **envelope and ventilation technologies** offer several paths to align efficiency and resilience. As discussed above, air sealing *complements* resilience by maintaining temperature in extreme cold. Mechanical ventilation can improve indoor air quality and alleviate rising temperatures in extreme heat. Vernacular designs (i.e., architecture specific to a locale) may represent centuries of lessons learned in sustainable, resilient, and efficient buildings appropriate for their region. Modern passive house designs similarly strive for efficiency and resilience, improving thermal efficiency, indoor air quality, and other comforts. These technologies can also lead to *conflict* between efficiency and resilience. Tight air-seals at the envelope, especially without mechanical ventilation, exacerbate thermal conditions, especially in extreme heat and can lead to moisture issues. Some highly insulating materials are also highly flammable, adding to fire vulnerability. Mechanical ventilation could be a point of failure that allows worsening indoor air quality, for example with smoke from wildfires. Passive house designs may include powered components like a heat recovery ventilator (HRV) or an energy recovery ventilator (ERV), which offer efficiency improvements, but require uninterruptible power supplies that could be a point of failure in a long duration power outage without sufficient back-up generation.

Building construction and retrofitting requires many considerations that intersect both resilience and efficiency practices. Energy efficiency technologies that rely on high-quality materials or buried utilities likely *complement* resilience (e.g., solar PV panels that are more resilient to hail than typical roofing materials). Many retrofitting efforts are *currently uncorrelated* because builders may not consider both goals at once. The siting of equipment installed to improve efficiency or load flexibility affects the resilience of the equipment (e.g., on the roof or at ground level). When owners chose to make retrofits to address resilience, such as earthquake retrofits, exterior hardening for impact protection, or pest control measures, they may miss opportunities to simultaneously improve efficiency (e.g., upgrade insulation while whiles are open).

Communities are typically essential for resilience as people support or rely on their neighbors in times of duress. Many local government efforts to ensure community resilience may be *currently uncorrelated* with efficiency though. Zoning and land-use planning may not consider opportunities for efficiency; emergency shelters or preparedness locations may not include efficiency in their operation plans. Grant programs through Housing and Urban Development (HUD) or the Federal Emergency Management Agency (FEMA) contain goals or standards for either efficiency or resilience but not always both.

Rainwater collection and wastewater management may add to resilience by managing flooding hazards or moisture issues but are *currently uncorrelated* potentially separate from energy efficiency concerns. In general, clean water supply to a building is essential for resilience but has little bearing on the efficiency of the building.

4. BREAKOUT SESSION 3: CHALLENGES AND OPPORTUNITIES

In the first part of this breakout session, participants in each group brainstormed various challenges to integrating energy efficiency or load flexibility technologies and practices with resilience technologies and practices. This discussion built on the exploration of the nexus between these two goals and sought to identify specific challenges preventing resolution of the conflict between efficiency and resilience as well as challenges hindering greater adoption of complementary technologies and practices. As the discussion evolved, challenges were grouped into categories for analysis. In the second part, participants explored opportunities to address the challenges. Both challenges and opportunities could relate to technical, market, policy, awareness, standards, or other issues.

Once each group had identified its list of opportunities, they voted to prioritize them within two categories—those with the greatest potential for long-term impact, and those that could be realized quickly (i.e., "quick wins"). The opportunities in each category were not required to be mutually exclusive. The Enclosures group, however, focused solely on the long-term impact dimension.

4.1 ENCLOSURES

4.1.1 Challenges

Challenges to integrating energy efficiency and load flexibility with resilience include: uncertainty in planning and prioritization; policy issues; uncertain costs and benefits; siloed efforts; lack of education and awareness; lack of modeling tools; grid issues; and knowledge and research gaps. Many of these challenges focus on difficulties understanding and aligning existing options for improving resilience or efficiency, rather than on any need for new technologies. Specific technology challenges related to enclosures are notably absent from this list possibly because many energy efficiency options appropriate for enclosures are maturing or commercialized but not extensively deployed. Existing building stock represents a significant portion of the U.S. infrastructure and deep retrofits are only so common. Similarly, many resilience technologies and techniques are well-established, but the benefits are too uncertain compared to the up-front costs. Technology challenges exist (e.g., building components that are designed to have soft fails and restarts), and this is an area where more input is needed.

Planning and Priorities

Energy efficiency, load flexibility, and resilience technologies represent a broad scope of concerns. There is a significant challenge to appropriately prioritize options and plan for future improvements. Building owners, policy makers, program managers, and other stakeholders must consider many location-specific risk factors such as hazard exposure, hazard vulnerability, the building type and its use, and the critical functions within the building when developing mitigation strategies to improve in both resilience and efficiency.

The context for planning also matters. Actions taken to mitigate the risk of a future disaster will differ from actions in the immediate aftermath when the focus is on ensuring shelter and protecting health. In any case, planning and prioritization takes time, effort, and funding—resources that are typically constrained. Finally, uncertainty in the return on investment persists in part because clear metrics for load flexibility and resilience are not widely available. Climate change exacerbates the uncertainty as granular impacts are especially difficult to define.

Codes and Policies

Codes and policies to enforce them establish a minimum level of quality and performance for new construction and deep retrofits. Improvements beyond the codes are not that common, so broad scale implementation of resilience and energy efficiency measures is likely limited to the minimum level set by local jurisdictions having authority to enforce the codes. Differences in the way states choose to adopt codes established by private standards organizations like the International Codes Council and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) can lead to inconsistency and conflict. "Home Rule" states empower local city or county governments to adopt codes through legislative or regulatory action, producing small variation from community to community. Finally, incentives established by policies may not be appropriately aligned with risks, which can promote activities that reduce resilience.

Cost/Benefits

Energy improvements may be evaluated based on a clear business case by estimating energy savings and evaluating associated reduction in monthly costs. Resilience investments, on the other hand, do not have well-defined payback periods and benefits may only be realized in the event of a disaster. Upfront costs for measures that improve efficiency and/or resilience can be steep, especially at the community level, but even investments in individual buildings may appear cost-prohibitive without clear understanding of the benefits. Insurance prices could reflect resilience investments, but this is not necessarily true everywhere or for all hazards. In any case, the value derived from improved resilience is difficult to measure given the impacts of disasters on human life and communities. Where efficiency and resilience measures complement each other, uncertainty in the value of benefits from either is a challenge to making investments that address either let alone both. Where measures may conflict and trade-offs are inevitable, lack of clear metrics impedes decision making.

Silos

Practitioners in the fields of energy efficiency, load flexibility, and resilience rarely overlap to a significant degree. Each effort has, to date, been pursued largely independently of the others despite complementary aspects. In the federal government, different agencies have responsibility for driving improvements in each field. For example, DOE has a primary role in energy efficiency research and development efforts, while FEMA takes the lead in planning for and responding to natural disasters, including through management of grant programs and other community investment. Other agencies including HUD, EPA, USGS, and NIST have roles in one or more of these fields, and funding for individual programs is likely tied to a single mission. State government agencies may be similarly siloed. In the private sector, design, manufacturing, construction, and operation may all focus on either resilience or efficiency, but few likely have expertise in both fields.

Lack of Education and Awareness

Many consumers are unaware of issues regarding energy efficiency, load flexibility, or resilience, which hinders informed decision-making and reduces buy-in. Designers, contractors, and owners similarly lack education and awareness on these issues, especially how they intersect, and therefore may not see a need to pursue integration of efficiency and resilience and will not educate their customers about the nexus of these issues. Curricula to train professionals in resilience and efficiency are likely not integrating the two subjects either. Resilience, in particular, is a broad field with somewhat amorphous definition depending on the source. The lack of a common understanding of resilience fractures efforts to integrate efficiency.

Modeling tools

Modeling tools exist for both resilience and energy efficiency/load flexibility, but they are not integrated to better model the interrelationship between measures to improve each. Performance verification for measures that complement both efficiency and resilience is therefore limited. Occupant behavior affects the performance of both measures, and may be difficult to model effectively, especially in resilience impacts.

Grid

Renewables and grid-scale energy storage have potential to improve grid resilience as well as energy efficiency and load flexibility, but as the business models for utilities evolve with further penetration of these technologies, existing policies regulating utilities may hinder deployment. For example, energy storage can provide ancillary services to the grid like frequency control and voltage regulation, but ratemaking policies or other barriers may not allow the energy storage owners, utilities or otherwise, to derive value from those services.

At the consumer end, onsite generation, especially solar PV may not be usable during a power outage, depending on the capabilities of the system and the interconnection agreement (i.e., the contract between the customer and the utility), which creates a challenge to improving resilience with this efficiency technology. Similarly, utilities rely on demand response to manage loads, but some resilience technologies could change load profiles.

Knowledge and Research Gaps

There are many outstanding research gaps that hinder integrating energy efficiency and resilience. One example is the lack of a low-carbon concrete binder. Portland cement, the key component of concrete, is both energy intensive and carbon intensive to produce, contributing to climate change. Concrete is a key enabler of resilient building enclosure construction, but the production of concrete exacerbates the need for resilient technologies.

Unknowns about existing building stock is another example of a gap in knowledge. Designs and specifications for older buildings are likely unavailable for building owners seeking to retrofit structures to mitigate risks from extreme events. The lack of knowledge of design loads and assumptions from the construction of the building is a barrier to introducing energy efficiency and resilience technologies and practices.

4.1.2 Opportunities

The highest priority opportunities to make game-changing[1] impact to better integrate energy efficiency into pre-disaster mitigation as well as post-disaster recovery activities lie in rating systems and codes. Other priority opportunities include defining the value proposition, greater education and awareness, greater collaboration, and new studies and tools. Further opportunities to address challenges are also described below.

Rating Systems

Consumers with limited experience in energy efficiency and resilience rely on **simplified ratings** to make decisions. FORTIFIED Homes and ENERGYSTAR appliances demonstrate the type of single metric that can help to inform consumers. There is an opportunity to develop rating systems for homes that could be used at the point of sale as an extra data point for making decisions. A simple "A" through "F" resilience score for a home could communicate that information succinctly. **Pictorial or symbolic systems** specific to natural hazard types (fire, wind, seismic, etc.) could add another level of detail and regional specificity. Any rating system will rely on **well-established and vetted metrics**. Stakeholder workshops and **pilot studies** can help to flesh out sensitivity for the rating scale as well as potential market impacts.

Codes

[1] Specific quick-win opportunities related to enclosures were not identified by participants during the workshop.

Hazard-based energy efficiency and resilience codes represent one of the clearest paths to encouraging uptake of measures that improve building enclosures. While there are opportunities to propose changes to model codes from standards bodies, there is also an opportunity to develop **overlay codes** that push beyond the requirements of current model code. Communities can then directly implement the overlay code, and aspects of the overlay code can influence future versions of model codes. Greater **coordination** between stakeholders in energy efficiency/load flexibility fields and those in resilience fields would support alignment of energy code with resilience goals. An **interagency code working group** (or an intra-agency working group, for example, among programs within DOE) could bridge the divide.

Codes generally update on a cycle that lasts several years. As climate change impacts change regional risks, codes may need to evolve. **Tools** to model weather shifts under multiple emissions scenarios from the Intergovernmental Panel on Climate Change could support private sector analysis of needed changes in codes.

Value Proposition/Business Case

Premiums for homeowners insurance, business insurance, medical insurance, and life insurance all provide clear and measurable levers to promote risk mitigation and resilience strategies. Discounts for installing resilience technologies and practices would establish a well-defined target cost for the installation that can underpin the business case for deploying such measures. The direct costs of an insurance plan may be only one piece of the value proposition of resilience and energy efficiency measures, however.

A value proposition for resilience and energy efficiency measures that looks beyond easily defined costs and benefits could resonate with developers and home owners. A **techno-economic analysis** of energy efficiency measures that includes benefits from improving resilience is needed to capture the full value of those measures. Finally, there is an opportunity to **leverage energy savings** based on well-established methods to value those savings (e.g., for energy savings performance contracts) in order to finance resilience improvements.

Collaboration

Given the siloed nature of energy efficiency and resilience practitioners in both the public and private sector, there is an opportunity to develop **collaborative teams** that bridge the divide (e.g., the inter- and intra-agency working groups discussed *infra* under "Codes"). Interagency collaboration would be beneficial at all points in preparing for and responding to a disaster. FEMA and DOE, for example, could coordinate to **build back better** in both measures post disaster. Collaborating on **assessments** after disasters could further highlight opportunities to strengthen resilience and energy efficiency.

Collaboration among private (and public) sector stakeholders—weather forecasters, mortgage companies, appraisers, insurance companies, first responders—could produce **co-branded and co-marketed products** to simultaneously improve both efficiency and resilience.

Education and Awareness

Education and awareness must extend beyond the obvious stakeholders in the resilience and energy efficiency communities to regulators, policy makers, and the general public. Outreach will depend on the audience. Emergency managers, insurance agencies, energy community stakeholders should see the latest knowledge and advancements to integrate resilience and efficiency; regulators should be aware of pilots that demonstrate benefits of integrating resilience and energy efficiency; homeowners should be aware of the potential costs, benefits, and trade-offs; construction workers should understand best practices and pitfalls of installation. For example, a series of resilience and energy efficiency business **case studies** would be informative. **Design guides** for various building types could describe safe, energy efficient, resilient building design. Basic **talking points** to explain the benefits of resilience and energy efficiency integration would create a unified message to the general public, and summaries of the existing knowledge in this space, geared to mass consumption, would offer further engagement on the topic. Like utilities' websites that explain and promote energy efficient projects as part of their efficiency programs, resilience technologies and practices should be cataloged and explained in an accessible format.

Studies and Tools

Since opportunities abound to improve resilience and efficiency individually, studies and tools are needed to better understand how to best take advantage of those opportunities in a coordinated fashion. Simple tools that can **quantify and assess resilience** would represent a quick win. Studies of the **impact of energy codes** on resilience (e.g., ability to shelter-in-place) would help to further define the nexus of efficiency and resilience. **Standardized methods** to qualify social impacts could help to frame the costs and benefits of resilience. Long-term, decision making tools that consider both energy efficiency and resilience quantitatively are needed.

Larger studies could demonstrate how energy efficiency and load flexibility technologies specifically complement resilience in different hazard scenarios (e.g., during a polar vortex, what is the impact to the resilience of a structure under high and low energy efficiency cases; how long can a facility operate with limited backup and fuel but varying efficiency measures incorporated in the building enclosure; how long are buildings habitable without power depending on the efficiency technologies installed?). Similarly, a set of **case studies** on the "lone building left standing" after a disaster could provide empirical evidence for successful best practices.

The National Institute of Building Sciences conducted a multi-year study titled "*Natural Hazards Mitigation Saves*" which is widely respected in the resilience community. An expansion of this study to develop an energy module, beyond their recent "Utilities and Transportation Infrastructure" report could support integration of energy efficiency and resilience into future buildings R&D efforts.

Pilot projects

Regionally specific hazards make developing a single set of recommendations impractical. A series of **pilot projects** to demonstrate integration of energy efficiency and resilience spread across different regions and subject to different climates and natural hazards could provide valuable data on costs and return on investment. Such projects should consider dynamic energy efficient windows, cool reflective paints, advanced insulation, and solar ready home equipment to demonstrate their potential. Similarly, **pilot programs** with homeowners and insurers could demonstrate the value of integrating resilience and energy efficiency and accelerate incorporating that value into insurance premiums to send a strong market signal.

Workforce Training

Workforce training workshops for builders and contractors would directly impact integration of resilience and efficiency by addressing awareness challenges. The funding set aside in the Stafford Act for pre-disaster resilience improvements to mitigate hazards could potentially support targeted **local training**. Such training could also cover concepts for resilience retrofits and post-disaster rebuilding combined with information about utility energy efficiency programs and rebates. For more formal education, **curricula** that combine efficiency and resilience should be included in professional degree programs and certifications for buildings sector workforce.

Structure and Components

Attics are a clear point of intersection for resilience and efficiency. An attic composed of fire-retardant materials that is resistant to uplift, and efficient with above deck insulation, a radiant barrier, and regionally appropriate ventilation could demonstrate the best of both resilience and efficiency. Similarly, **safe rooms** are a well-established resilience technique that could be integrated with thermal storage, for example. Smart use of thermal mass for energy efficiency and resilience would be a foolproof asset in the event of a power outage. Highly insulating, **impact resistant windows** could be promoted for both efficiency and resilience benefits. **Automated roller shades** or shutters could respond to reduce energy demand as well as to mitigate developing hazards.

Priority Opportunities for Buildings Envelope

Opportunities with Greatest Impact Potential

- Develop simple, broadly adopted rating systems
- Develop model or overlay codes
- Define the value proposition for resilience and energy efficiency
- Provide for greater education and awareness of the nexus between resilience and energy efficiency
- Encourage greater collaboration among stakeholders: among Federal and State government agencies, among private sector industries, and between public and private sectors

4.2 OPERATIONS

4.2.1 Challenges

Knowledge and awareness

Knowledge and awareness of how resilience and efficiency in buildings relate, why it matters, and what can be done to improve resilience and efficiency simultaneously are foundational challenges underlying many barriers to integrating resilience with efficient technologies and operations. Developers, policymakers, standards organizations, and influencers simply do not have enough information to take action. And when they are presented with information about resilience and efficiency, the issue is complex and nuanced. There are insufficient resources and tools to help them understand what needs to be done in their specific circumstance. There is a lack of tools to help both government officials and private sector understand the extent of their resilience needs and how this could affect the energy efficiency/load flexibility of their buildings or community more broadly. In particular, while some inroads have been made toward improving energy efficiency in economically disadvantaged and vulnerable communities, there is insufficient attention to resilience needs. There is a lack of building resilience-efficiency knowledge of decision-makers in general, including government leadership, builders/developers, insurance industry, utilities, and community organizers. Post-disaster, in particular, there is a lack of institutional knowledge about how building design and operations can affect response and recovery.

From an operations standpoint, behavioral barriers, such as the inertia to keep things the way they are, also prevents builders and building operators from making changes to improve building resilience. It is easier for many owners and operators to justify adopting energy efficiency measures than resilience measures. Risk communications presents another behavioral challenge for resilience; how to communicate the probability that a range of adverse outcomes may occur is difficult to explain, until after a disaster has occurred.

The lack of workforce development training inhibits progress. From a technical perspective, it is difficult to train staff on determining what actions are required to maximize resilience during operations and maintenance of energy efficient and load-flexible technologies such as CHP and microgrids, for example.

Resilience Modeling

Lack of resilience modeling is preventing the analytical backing needed to address knowledge challenges. There is insufficient modeling to determine the best course of action—whether during design phase, during a disaster, or post-event—in regard to improving resilience and how efficiency/load flexibility contributes. The modeling could be scenario-based and linked to design investments or operations parameters. There is also a lack of real-time models to determine what is the best course of action for specific buildings and operations (e.g., guidance on whether to open windows, evacuate) using real data and actual hazard circumstances (e.g., wildfire, heat wave, lack of power). There are no known models that can determine what an ideal energy efficient and resilient system/envelope/technology would entail, which hampers decision-makers' ability to set targets for a given region, population density, urban/rural, central/distributed, building type, and so on.

Costs

High cost of technologies, implementation, and workforce development/training is a significant challenge. There are limited public financial incentives for developers to increase resilience to many hazards, and many customers (e.g., home buyers, commercial building owners) do not value the benefits of resilience enough to justify the additional cost. Incorporating resilience and efficiency in retrofits, in particular, is costly and much more difficult than for new structures. Retrofits can force people to temporarily leave homes or lose business. The scale of this challenge is significant since the vast majority of the U.S. building stock is existing structures.

Collaboration

Lack of collaboration among communities, utilities, policymakers, researchers, builders, and customers exacerbates the challenge of integrating resilience with energy efficiency and load flexibility. There are split incentives between some stakeholders, such as the building owners and tenants. Research and funding silos separate different groups and hinders collaborations, making it more difficult to secure funding for research and other efforts to address resilience/efficiency challenges. Some load flexibility and resilience technologies, such as rooftop PVs and batteries, may increase fire risk and introduce a coordination challenge with fire departments and equipment manufacturers.

Valuation Measurement

Methods for valuing resilience in buildings are inadequate. There is no agreed, standardized metrics or methodology for evaluating and determining the monetary value of a building's resilience, and there are no standard measurements for incorporating energy efficiency into a resilience methodology. This is a barrier that contributes to several other challenges, including justifying the high cost of implementing resilience solutions and the lack of knowledge and awareness of the benefits of resilience. Without building resilience measurements, it is difficult to estimate returns on investment. The challenge is magnified in that resilience can improve or decrease energy efficiency and load flexibility, and it is complicated in that resilience benefits can be accrued through long-term (chronic) improvements as well as immediate (acute) resistance to disaster events. Without agreed metrics it is also difficult to determine what level of resilience is best or necessary for certain structures and communities. In other words, the lack of resilience metrics makes it difficult to develop cost-benefit assessment to ensure the "right" level of investment for resilience. The lack of addressing this challenge inhibits the ability to move forward with addressing other needs.

Building Complexity and Design

The complexity of buildings creates technical and design challenges for improving resilience in energy-efficient buildings. Smart buildings and the increasing number of controls and complexity of controls, while improving comfort and efficiency, can create technological challenges for resilience. In some circumstances, active controls improve resilience but in others, or when there are power outages, the controls in the building make improving resilience more difficult. Similarly, energy efficiency technologies that rely on active controls or Internet connectivity can also be compromised by power outage or major disruption. There is also a challenge in using and analyzing the increasingly vast amounts of data collected from buildings to improve the resilience and efficiency of buildings.

Retrofitting buildings with advanced resilience equipment is also a significant technical challenge. The building stock varies widely in age, designs, purposes, and locations, and designing and implementing technology solutions that work in each of these circumstances and to mitigate against a range of hazards could be a monumental undertaking. The pace of change in retrofits is slow; they are rarely upgraded. There is currently a lack of codes that incorporate resilience, and so even when retrofits are upgraded there is no standard master planning or platform for monitoring or improving resilience. And when new structures are designed, rarely do builders incorporate resilience-enhancing solutions.

Energy "Routing"

Energy "routing," or the site share of electrical distribution systems, is an important resilience challenge in buildings. From a systems view, electrical distribution systems do not segregate against critical versus non critical loads, and so essential services such as water pumping stations or emergency response facilities are not prioritized in a disaster situation. In addition, and hospitals and nursing homes are not able to share power because it is an infringement on the utility rights. Transmission access charges are increasing, which is deterrent for local and distributed energy systems.

Interoperability with grid systems can improve building resilience but also creates complexity for builders and owners that can be a challenge. Building occupants increasingly expect to be able to disconnect from the utility power supply in times of outages. In addition, building and equipment contracts and warranties may need to incorporate resilience and efficiency provisions.

4.2.2 Opportunities

The high-priority opportunities to make game-changing impacts on the operations side lie in technology R&D and resilience valuation. The high-priority opportunities for quick-wins lie in knowledge and awareness, financing and incentives, , collaboration, and resilience valuation. The list of specific opportunities is presented at the end of this section. Other areas of opportunity to address challenges include smart systems, structures and modular buildings, codes and standards, and "low-tech" guidance, which are further described below.

Technology R&D

Technology R&D, such as advancements in **combined heat and power (CHP)** technologies present a large-scale resilience opportunity that is currently underutilized at the community scale. Approximately 40GW of building integrated CHP and storage are unused in the United States. CHP could also be used with onsite renewable fuels to improve the resilience and carbon footprint. **Next generation HVAC/RTU** (roof top unit) is a technology research opportunity to create efficient, grid-interactive buildings equipment that supports resilience. The redesigned units would consider both resilience and efficiency in the design and would require new thermal designs, advanced controls, power electronics, and interconnects. Additional R&D opportunities include research on **advanced materials** that are more resilient and are useful in efficient technologies. In general, building science research around the resilience-efficiency nexus is needed, including testing, that would incorporate use-cases for different operating conditions.

Resilience Valuation

Standardizing the value of resilience is an opportunity to address multiple resilience implementation challenges. Such a standard, or agreed set of metrics, could be **community benchmarks** that bundle energy efficiency and resilience and incorporate the complexities associated with the circumstances in which the building is located, used, operated, and hazards it is exposed to. In addition, **modeling** is an important supporting element for developing trusted estimates regarding the value of resilience. Resilience has the opportunity to become an **additional value proposition** for technologies and systems if it can be reliably quantified, valued, and trusted by stakeholders. Generating resilience metrics is difficult to address at once, and so certain aspects or use scenarios (e.g., residential single-family structures in given climate zones) may need to be examined separately at first.

Knowledge and Awareness

Improving knowledge and awareness offers opportunities to improve resilience and energy efficiency/load flexibility in buildings. This includes providing reliable resources for stakeholder engagement, outreach, and supporting resources/tools. Opportunities for resources and tools include development of a **collaborative report**—which could be led by the Department of Energy in coordination with research labs and private sector building interests—focusing on building technologies that are resilient and energy efficient/load flexible. The report could be used as input to incorporate resilience topics into existing and future **Advanced Energy Design Guides**. The report, as well as efforts to develop standardized resilience metrics (see below), could be used to reach consumers when buying and selling homes, such as a **resilience MLS indicator**. Additional awareness efforts regarding consumer demand include educating the residential and commercial appraisal industry regarding the value of resilience and influence on property value. **Workforce education** programs targeted for buildings stakeholders could address lack of specialized knowledge. **Fact sheets** about specific technologies are also needed. For example, passive design structures are often recognized as energy efficient, but the resilience impact is not understood. Communications products could be “fun,” so that resilience is viewed as an attractive feature rather than “bunkering.” Consider developing tools that are **games** that offer combinations of technologies and practices to improve both energy efficiency and resilience, based on circumstances of the user and building. When developing communications resources, the benefits should be carefully conveyed as dependent on the situation (e.g., climate zone, hazard, and building type).

Financing and Incentives

Financing and incentives represent an opportunity to create demand for buildings resilience. Energy efficiency measures can be used as a model for how resilience could become incorporated into **lending programs**. For example, Fannie Mae and Freddie Mac have programs that incentivize energy efficiency, and there may be an opportunity to augment these programs for resilience or create a resilience program based on the success of energy efficiency programs. Similarly, the Federal Housing Finance Agency offered reductions in mortgage points for borrowers who can demonstrate use of energy efficiency measures. **Education, supporting data, and use-cases** would be helpful in presenting resilience benefits needed to support such efforts. The Federal Housing Administration represents another potential stakeholder that could be interested. Financial opportunities are well suited for resilience solutions in buildings because of the longer payback periods of some resilience technologies and because such investments are often made when home financing/mortgages or commercial financing for build-outs are secured. **Expanding the utilization of PACE** (Property Assessed Clean Energy) to include resilience is an opportunity to address the limited availability of financing for resilience measures. Initial work is underway to explore the PACE-resilience opportunity further. There could be a related opportunity to coordinate with state and federal disaster prevention and response authorities, such as the Federal Emergency Management Agency regarding resilience.

Collaboration

Collaboration among various stakeholders and decision makers can enable numerous opportunities for improving resilience in buildings. Developing **public-private partnerships** to improve energy management interoperability with engineering could address both technical challenges and limitations in knowledge/awareness. Collaboration between communities and utilities to align energy efficiency and resilience, such as an ongoing case study in Colorado, has potential to lay the groundwork for incorporating resilience in **utility planning** and goals. Additionally, connecting municipal governments with resilience-oriented non-profits and other organizations can forge lasting relationships that result in a conduit for sharing resilience and energy efficiency information and deploying new technologies, improving resilience for communities. From a strategic standpoint, developing logic models to identify the activities, outputs, and desired end goals can help identify external partners that can be essential in overcoming key institutional and awareness barriers to increased buildings resilience.

Smart Systems

Technologies such as smart systems and use of artificial intelligence (AI) and big data present research and development opportunities to improve resilience with energy efficiency and/or load flexibility. Data from inexpensive **sensors** could be harnessed and analyzed using AI and machine learning and inform **controls** that improve operations such that it benefits both energy efficiency and resilience. Similar to demand-side management of power during heat events, advanced sensors and controls may present an opportunity for users to operate in reduced mode if needed. Better sensor technology in buildings and an expanded network of sensors are research opportunities. In individual structures, advanced sensors and controls of building equipment could enable improved efficiency and resilience through sophisticated partitioning technologies to maximize limited generation—for example, during hurricanes or heat waves to cool only a portion of a building. More broadly, interconnections between buildings and emergency broadcast infrastructure (e.g., via the **internet of things**) could enhance resilience of energy efficient structures, which are often more modern and already equipped with communications technology. For example, the National Oceanic and Atmospheric Administration has dedicated servers available to share emergency messages.

Structures and Modular Buildings

In new construction of structures and modular buildings, there are broad opportunities for better technologies and designs that enhance both energy efficiency and resilience. Rather than considering resilience and efficiency after design or development phases, if the problem was presented to buildings designers and engineers as a coupled issue, there would be new solutions currently not available when considered separately.

Codes and Standards

Building codes and equipment standards are proven tools for implementing new and advanced technologies and practices that benefit consumers and communities. Existing energy standards for appliances, for example, might present an opportunity or model for resilience codes. Specialized building codes for resilience could be incorporated by zone or hazard area.

"Low-Tech" Guidance

Low-tech, or 'do it yourself' solutions can improve resilience in buildings even if the 'high-tech' equipment fails. There is an opportunity to provide individuals with simple guidance on using or developing basic solutions using widely available supplies. Rather than solely relying on costly solutions for the grid, onsite measures could augment resilience capabilities through the use of items such as a swamp cooler, ice cooler box, small batteries, gas grill, or simply use of a basement. In addition, making available or encouraging stocking of inexpensive portable devices (e.g., powered by PV cells) in homes and businesses for charging phones, for operating radios, or even for boiling water would also improve resilience.

Results of workshop participants prioritization of the opportunities with the greatest impact potential and quick win potential are shown in the table below.

Priority Opportunities for Buildings Operations

Opportunities with Greatest Impact Potential

- Next generation HVAC/RTU design and advanced system technologies
- Community standards/benchmarks and valuation of energy efficiency and resilience
- Resilience incentives for insurers
- R&D of cost-effective solutions that complement energy efficiency and resilience (especially portable devices)
- Model methodology and development for valuing resilience
- Coordinating zoning and building codes with energy efficiency and resilience

Opportunities with Quick Win Potential

- Create an energy efficiency and resilience design guide
- Update workforce & education programs for resilience needs of vulnerable communities
- Address high costs & financing (e.g., long-term investors, market vehicles)
- Align resilience with utility goals
- Research to develop standards/benchmarks for valuing energy flexibility for resilience
- Resilience incentives for insurers

5. ACTION PLANNING

High-priority game-changing and quick-win opportunities require detailed action plans for implementation. These action plans define and describe the opportunity in greater detail by identifying the key challenges that would be addressed by pursing the opportunity, the desired outcome (including beneficiaries), and the milestones and actions needed to achieve the opportunity. Finally, actions must be taken by someone or some organization, so appropriate collaborators who could pursue the opportunity, including which entity or entities would be best suited to lead the effort, are also identified.

Priority opportunities related to ***building enclosures*** to better integrate energy efficiency and resilience in planning include the following.

- **Review Adoption/Modification of Existing Above-Code Programs**: Evaluate existing code programs outside the United States modify them for U.S. region-specific best practices.
- **Advancing Codes to address resilience holistically**: Explore how to leverage existing code frameworks to think holistically on delivering community resilience to include continued operations, community social and economic infrastructure, and changing risks.
- **Tools and analyses to characterize linkages among energy efficiency, load flexibility, and resilience:** Build the tools and analysis needed to study linkages among these goals specific for individual facilities, communities, or broader geographic regions.
- **Public-facing education and awareness:** Create uniform messaging for resilience that buildings owners can trust and integrate messaging it into appropriate touchpoints for energy efficiency.
- **Rating System:** Develop a residential and commercial rating system for resilience in buildings that is rigorous, comprehensive, regionally appropriate, and trusted.
- **Development of Resilience Value Proposition for Diverse Stakeholders:** define the value of resilient design while performing energy efficiency measures to the homeowner or community.

Priority opportunities related to ***building operations*** include the following.

- **Incentivize this! Insurance & underwriter resilience incentives:** accelerate awareness of resilience measures among insurance carriers and their underwriters to better align insurance premium pricing structures and payouts with mitigation of risk factors, including efficiency.
- **Create an energy efficiency & resilience (EER) utility:** Develop new utility business models that incorporate emerging technologies for energy efficiency and resilience while promoting decarbonization, addressing climate threats, and educating stakeholders.
- **Show me the money! Methodology for the valuation of resilience and co-optimization with energy efficiency:** Develop methodology to enable consensus on the value of resilience to different market segments and actors including utilities, builders, codes and standards bodies, and communities.
- **Publish Advanced Energy and Resilience Design Guides (AERDG):** Add, include, and/or enhance resilience topics in existing and future design guides and publicize them.
- **Create Resilience Benchmarking for Zoning & Building Codes:** Develop clear benchmarks, in a written guidance format that is widely adopted, for building codes/zoning that communities and developers can plan/finance around.

- **Up the PACE—Integrate resilience in PACE financing:** Create additional financing opportunities beyond traditional PACE financing by incorporating resilience measures.
- **Cost-Effective "DIY" Package and Solutions:** Develop guides and look-books containing cost-effective solutions for integrating resilience and energy efficiency into residential or commercial buildings, appropriate for their climate zone.
- **Grid Friendly, Resilient, Efficient HVAC/RTU, hot water heaters, and air distribution systems:** Design and develop next generation replacements for common energy intensive systems that also contribute to resilience of the building and the grid.
- **Actionable Resilience Information for American Businesses:** Catalogue and incorporate resilience information into other guides and tools BTO commonly uses to communicate energy efficiency implications of actions.

The opportunities explored in small groups represent specific ideas from various categories discussed in the previous section. Activities pursued in each category will likely have effects on others. One possible framework for these interrelationships is shown in figure 1.

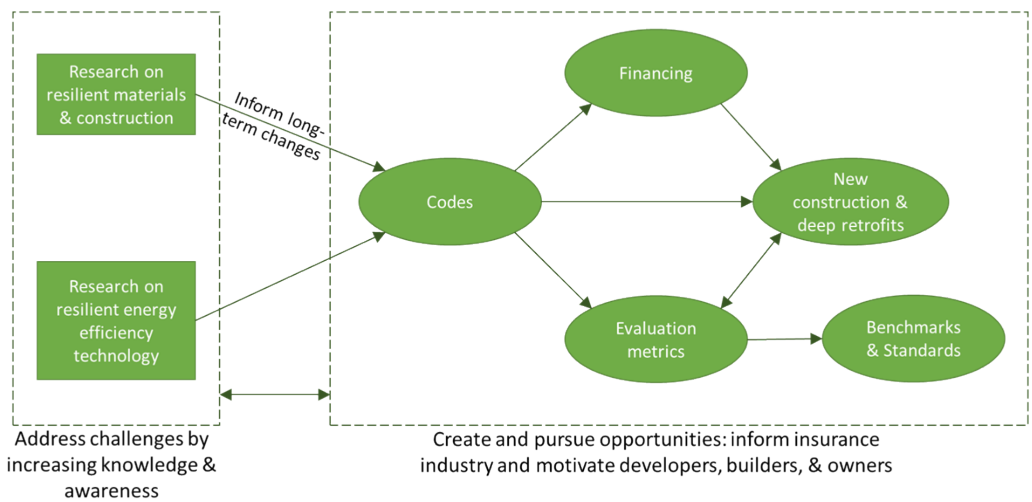

Figure 1. One potential framework to consider the interrelationships of challenge and opportunity areas.

5.1 ENCLOSURES

Review Adoption/Modification of Existing Above-Code Programs			BIG IMPACT
Description	• Several non-US systems exist that value assessment of resilience during design • Evaluation and adoption (with possible modification) would speed the ability to implement such a program in the United States. • A program with several scenarios based on location (local risks and climate zones) can recommend the best practices for different parts of the United States.		
Desired Outcome		**Key Challenges Addressed**	
1. Understand which model codes/ratings are assessing risk as part of the pre-design/design/permitting process. 2. Pilot demo project(s) to demonstrate energy efficiency and resilience in each qualified zone a. Collect data and publish b. Cost and ROI		Depending on the location, hopefully will address all building structure and building location risk factors	

Tasks and Milestones

Milestone(s)	Task(s)	Schedule(s)
Literature review	DOE Labs perform literature review	12 months
Pilot Projects	DOE Labs undertake pilot projects	Begin 1 year → 5 years+
Outreach to builders (developers, engineers, National Association of Home Builders [NAHB], code officials)	REOs, ICC, NAHB, BOMA, associations of developers, Council of Mayors, state energy agencies, FEMA, Insurance industry, Chief Res. And Sus., community foundations coordinate outreach to builders.	12 months +

Lead Stakeholder(s)	Other Stakeholders	Role
	DOE/BTO	
	National Labs	
	Other Fed. Gov.	
	State/Local Gov.	
	Communities	
	Utilities/PUCs	
	Emergency Managers	
	Builders & Manufacturers	
	Owners	
	Occupants	
	Academia	
	Other	

Advancing codes to address resilience holistically with a path to continued development	**BIG IMPACT**
Description	• Codes are a widely used approach to address specific safety requirements including hazard protection and energy efficiency. • How do we leverage this existing framework to think holistically on delivering community resilience? • How do we expand codes to move beyond immediate life safety to include continued operations, community social and economic infrastructure, and changing risks?

Desired Outcome(s)	**Key Challenge(s) Addressed**
• Holistic approach to resilience that includes energy as part of the code-based strategy • Greater clarity in risk profiles/maps and tie to specific code provisions • Pathways to address evolving risk with existing/evolved code structure • Incorporate lessons learned from ratings system into codes.	• Bring coordination to process through identified resilience strategies with IBC/IRC to include energy • Useful criteria to allow consistency and map progress

Tasks and Milestones

Milestone(s)	**Task(s)**	**Schedule(s)**
Commentary on how code provisions contribute to resilience, parallel user guide	• Labs and code developers review code provisions • Develop user guide for code considering resilience and energy together	~1 year
Code proposals for 2024 that are coordinated around resilience concepts	• Collaboration on proposals (DOE, Regional Energy Efficiency Networks [REEOs], etc.)	2019 → 2022
Overlay code that includes enhanced resilience, social and economic resilience, immediate occupancy/functional recovery, evolving risk	• Labs and code developers, researchers • Standards development process	Post 2021 development - ongoing
Education and training on new approach/provisions	• Parallel with commentary development	~1.5 years

Lead Stakeholder(s)

- Federal interagency working group
- Efficiency community and hazards community
- Code development organizations

(these are the leaders, who should engage groups at right)

Other Stakeholders	**Role**
DOE/BTO	and REEOs
National Labs	
Other Fed. Gov.	E.g., FEMA, HUD, NIST, NOAA, USGS, USFS
State/Local Gov.	E.g., Ins. Office, PUCs, Emergency Plan, Energy Offices
Communities	E.g., Chamber of Commerce
Utilities/PUCs	
Emergency Managers	E.g., NEMA, IAEM
Builders & Manufacturers	

	Owners	E.g., GSA, DOD, IHS, USACE
	Occupants	E.g., HOAs, BOMA, Realtors
	Academia	
	Other	Insurance/ISO Finance Code developers (ICC/ASHRAE)

Tools and analyses to characterize linkages among energy efficiency, load flexibility, and resilience	**BIG IMPACT**
Description	Linkages need to be studied to establish how energy efficiency and load flexibility does or doesn't contribute to resilience, whether individual facilities, communities or broader geographic regions. e.g., polar vortex or heat wave impacts under higher or lower levels of EE e.g., FL nursing home case – answer whether more EE would have helped

Desired Outcome(s)	**Key Challenge(s) Addressed**

• Understand and quantify EE + Load Flexibility impacts (benefits + costs) on resilience
• Use this information to inform other activities
  ○ Valuation(!)
  ○ R&D Agenda
  ○ Investments
  ○ Codes, Standards, ratings
  ○ Education and trainings
  ○ Policy
	• Lack of:
	  ○ Tools to inform designs
	  ○ Metrics and methods
	  ○ Impact assessment (e.g., cost-benefit)

Tasks and Milestones

Milestone(s)	**Task(s)**	**Time Frame**

(1) Categorize resilience threats that directly relate to building energy consumption:
• Temperature
• Flooding
• Power outages
	• Characterization/feedback on resilience threats:
	  ○ Broader stakeholder engagement
	  ○ National labs for studies
	  ○ Prioritization of risks
		1 year

(2) Analysis that shows energy efficiency matters
• EE and New England/Midwest with polar vortex
• EE and nursing home
• Heat wave in Chicago
	• Launch analyses ← funding allocated
	  ○ Collect data
	  ○ Run scenarios
		1-2 years

(3) User Eval Tools: • Develop metrics • Compile cost information • Create user tools	• Refine existing tools/design new tools • Promote tools	1-3 years

Lead Stakeholder(s)	**Other Stakeholders**	**Role**
BTO develops call for research proposals with feedback from other stakeholders.	DOE/BTO	$, convening, coordination, prioritization
	National Labs	Research, data, "use our studies and tools"
	Other Fed. Gov.	
	State/Local Gov.	Feedback, "use our studies and tools," data
	Communities	Feedback, data, participation, use the tools
	Utilities/PUCs	Feedback, data, use the tools
	Emergency Managers	

	Builders & Manufacturers	Use the tools
	Owners	Use the tools
	Occupants	Receive education
	Academia	Research
	Other: Architects and Engineers	Feedback

Public-facing education and awareness	BIG IMPACT
Description	• Create messaging that buildings owners can trust, and processes for resilience identification that people can trust. • Integrate this messaging into various touchpoints, and integrate with efficiency measures

Desired Outcome(s)	Key Challenge(s) Addressed
• A high degree of awareness among building owners and residents about local climate impacts and detailed understanding of resilience measures needed • Building owners that are empowered to ask for resilient construction and ask for resilient options	• Missed opportunities to integrate resilience and energy efficiency when people are doing construction and renovation • Need to create market demand for resilient construction • Need for trusted information

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
• Local governments / regional officials deliver materials to promote awareness of hazards, resilience, and efficiency measures • Federal support with technical assistance to deliver and develop these materials • Align existing efficiency training and resilience training with contractor training	• Deliver information at key times before and after a disaster • Deliver information at time of home renovation and purchase • Align with utilities' energy efficiency programs • Create a template by threat • Create a toolkit for municipalities to disseminate information	

Lead Stakeholder(s)	Other Stakeholders	Role
Cities and towns State government Alignment with efficiency programs Regional non-profits Contractors and builders Incorporate into education.	DOE/BTO	Technical assistance and funding
	National Labs	Technical assistance and funding
	Other Fed. Gov.	Technical assistance and funding
	State/Local Gov.	Deliver programs and information to public
	Communities	Deliver programs and information to public
	Utilities/PUCs	Contractor training, marketing
	Emergency Managers	
	Builders & Manufacturers	
	Owners	
	Occupants	
	Academia	Research, technical assistance, curricula
	Other	Non-profits for community outreach, technical assistance

Rating System			Big Impact
Description	Residential and commercial rating system for resilience in buildings that is rigorous, comprehensive, regionally appropriate, and trusted		

Desired Outcome(s)	Key Challenge(s) Addressed
• Insurers recognize value for resilience • Appraisers recognize value for resilience • Consumer recognize value for resilience • Builders/developers • Builders/developers not-resistant to include resilience in buildings • Rating delivery infrastructure	• Clearer metrics • Standard methods and tools to value resilience • Recognizing value in transportation • Lack of education and awareness • Lack of resilience warrantees

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
Publication of Resilience Rating Plan/Report from summit	• Plan and implement a resilience rating summit – identify LEAD • Write report and plan details for moving forward	• 3 months • 1 month
Draft and Final Develop Rating System	• Draft, vet, and finalize the rating system	
Pilot Rating Program	• Create and run a pilot program for the rating system. • Determine whether Stafford and Disaster Recovery Reform Act funds can be accessible to rating system	• 2 years
Final Rating Launch	• Develop Rating Delivery Infrastructure • Consumer Awareness campaign • Builder/developer outreach and recruiting	Ongoing after pilot Total: 3 years.

Lead Stakeholder(s)	Other Stakeholders	Role
USGBC/LEED	DOE/BTO	Lead – facilitate summit
Fortified Home/IBHS	National Labs	Support
HERS/RESNET	Other Fed. Gov.	FEMA, HUD, DHS – Resilience
Appraisal institution/foundations	State/Local Gov.	Participate
Insurance associations	Communities	Participate
NAHB/National Green Building standards	Utilities/PUCs	Participate
Facility Manager (BOMA)	Emergency Managers	Participate
AIA	Builders & Manufacturers	Participate
ASHRAE	Owners	Participate
American Society for Civil Engineering	Occupants	
FEMA	Academia	
National Association of Realtors	Other	See "Lead Stakeholders"

<table>
<tr><th colspan="3">Development of Resilience Value Proposition for Diverse Stakeholders</th><th>BIG IMPACT</th></tr>
<tr><td>Description</td><td colspan="3">The opportunity is to define the value of resilient design while performing energy efficiency measure to the homeowner or community</td></tr>
<tr><td colspan="2">Desired Outcome(s)</td><td colspan="2">Key Challenge(s) Addressed</td></tr>
<tr><td colspan="2">• Lower operating costs
  ○ techno-economic analysis
  ○ Lower insurance costs
  ○ Distribute operations for communities
  ○ Less financial disruptions
  ○ Healthier buildings
  ○ Reduction in recovery time
• Lower environmental impact
• Sustainable communities at work
• Affordable solutions</td><td colspan="2">• Doing this includes efficiency when doing resilient measures.
• Getting buy-in from many stakeholders
  ○ Insurance cos.
  ○ Homeowner
  ○ Design community
  ○ Utilities
  ○ Contractors</td></tr>
<tr><td colspan="4">Tasks and Milestones</td></tr>
<tr><td>Milestone(s)</td><td colspan="2">Task(s)</td><td>Time Frame</td></tr>
<tr><td>Value Propositions for different stakeholders developed</td><td colspan="2">• Develop preliminary value propositions for different stakeholders
• test them, and modify as needed</td><td></td></tr>
<tr><td>Baselines defined</td><td colspan="2">• Integrating research and tools with valuation streams
• Engage stakeholders
• Iterate</td><td></td></tr>
<tr><td>Resilience value demonstrated to key stakeholders</td><td colspan="2">• Articulate and demonstrate the value of resilience to insurance, homeowners, builders, etc.</td><td></td></tr>
<tr><td>Requirements established</td><td colspan="2">• Prescriptive codes, insurance mandates</td><td></td></tr>
<tr><td colspan="2">Lead Stakeholder(s)</td><td>Other Stakeholders</td><td>Role</td></tr>
<tr><td colspan="2" rowspan="12">Insurance associations
Construction material/systems manufacturers
Passive house associations (e.g., Passive House Institute U.S.)
DOE and National Labs
HUD</td><td>DOE/BTO</td><td></td></tr>
<tr><td>National Labs</td><td></td></tr>
<tr><td>Other Fed. Gov.</td><td></td></tr>
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<tr><td>Occupants</td><td></td></tr>
<tr><td>Academia</td><td></td></tr>
<tr><td>Other</td><td></td></tr>
</table>

5.2 OPERATIONS

Incentivize This! Insurance & underwriter resilience incentives		BIG IMPACT
Description	To accelerate awareness of resilience, insurance carriers and their underwriters need to understand and evaluate the risk factors associated with resilience. By understanding these factors, underwriters will hopefully revise their pricing structure for insurance premiums and payouts based on the mitigation of these risk factors. These factors include location, climate, building typology, level of efficiency, and ability to withstand the traumatic event and be reusable afterwards with minimal downtime.	

Desired Outcome(s)	Key Challenge(s) Addressed
• Increased demand for resilience • New pricing structure to incentivize resilience measures in new and existing construction • Engagement between insurers/underwriters and building science community	• No known pricing structures • Little knowledge and lack of standardization of resilience

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
Engagement with insurance	Understand current pricing structures and risk factors	6-12 months
	• What do they know right now and how does it factor into decision-making?	
	• What is their timeframe?	1-2 years
	• What additional research is needed?	6-12 months
	• What are their losses and what mitigations have the most impact?	
Engagement with large property owners and developers	Verify if insurance premiums affect their decision making when buying/selling properties • Is this a pain point? • Will need to meet with initial developers and long-term holders.	6-12 months

Lead Stakeholder(s)	Other Stakeholders	Role
DOE should initiate industry outreach.	DOE/BTO	
	National Labs	Lead
	Other Fed. Gov.	
	State/Local Gov.	
	Communities	
	Utilities	
	Emergency Managers	
	Builders & Manufacturers	
	Owners	Participate
	Occupants	
	Academia	
	Other	Insurance – possible co-lead

Create an Energy Efficiency & Resilience (EER) Utility — QUICK WIN

Description

- Develop new business models which incorporate emerging technology
- Develop strategies to achieve decarbonization goals
- Develop strategies to promote electrification of end uses
- Develop strategies for emerging climate threats
- Develop strategies for commercial and industrial vs. residential
- Develop education/outreach for end users and contractors
- Develop more DERs in portfolio

Desired Outcome(s)	Key Challenge(s) Addressed
• Develop replicable sub-station level microgrid model utilizing efficiency measures and DERs (renewables) • Identifying "sweet spot" technologies that provide energy efficiency and grid benefits • Integration of high EV adoption and use as a grid asset (bi-directional power flow) • Develop new DERs utility model that is highly resilient, efficient, and equitable for all	• PUC models to allow utilities to become viable/profitable DSO's • Separate technical challenges from regulatory challenges • Lack of data on resilience programs (infrastructure investments) • Timing of EV charge/discharge • Identifying customer needs/addressing equity • Redefine "energy efficiency" in context of renewable vs. non

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
• Flatten "duck curve" • VOR is factored into rate rise	• Catalogue existing or planned deployments at community scale – incorporating energy efficiency and electricity and DERs	6 months +
• Consensus on energy efficiency in context of decarbonization and resilience priorities	• Redefine EE in context of carbon • Gather/analyze relevant data • Working group of Fed and State officials to discuss shared resilience priorities.	1 year Ongoing

Lead Stakeholder(s)	Other Stakeholders	Role
DOE/BTO	DOE/BTO	FOA
	National Labs	Test and ok new tech/validation
	Other Fed. Gov.	FEMA, DoD, DHS (pilots/$)
	State/Local Gov.	SEO, PUC, local/sustainability offices
	Communities	
	Utilities	R&D on adaptability of existing vs. new infrastructure
	Emergency Managers	
	Builders & Manufacturers	Removing barriers to adoption
	Owners	Identifying/prioritizing needs for resilience
	Occupants	
	Academia	R&D, modeling, studies
	Other	

Show me the money! Methodology for the valuation of resilience and co-optimization with energy efficiency

BIG IMPACT

Description

"To enable consensus on the value of resilience to different market segments and actors"

Utilities:
- Climate Zone
- Transmission or distribution connection
- Regulated vs unregulated market
- Commercial vs residential (vs industrial)
- Business model (recovery mechanism)
- Regional vulnerability to extreme events (hurricanes, tornadoes, flooding, earthquake, fire, high winds)

Builders:
- Safety (perception)
- Compliance with local safety requirement (earthquake)
- Marketing as a resilient builder

Desired Outcome(s)

Utilities:
- Prevent outages (esp. from weather)
- Decrease time to recover
- Value and recover cost for resilience
- Microgrids

Builders:
- Sell more building
- Upscale

Codes and Standards Bodies:
- More resilient built environment
- Sell more standards

Communities:
- Safer homes
- Connectedness/social capital
- Emergency preparedness

Key Challenge(s) Addressed

- Consensus (vs. diverse and unique methods)
- Simplification (currently complex)
- Clarity (vs current confusion) Esp. the link between resilience and EE/LF
- Structured taxonomy of risk
- Market action (vs inaction)

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
List of resilience metrics and equations for each key stakeholder	• Literature review of methodology • Interviews with stakeholders (define who those are) • Interviews of other agencies (NASA, DoD, USAF, armed services)	½ - 1 year
Taxonomy of risk with input, odds of damage (probability), damage amount (severity), and cost of resilience	• Define resilience metrics (BCL) • Database of resilience implementation cost • Quantify risk taxonomy table (beware regression against historical data amidst more extreme events)	2 years (Total: 3)
Benefits (or costs) of resilience for stakeholders	• Report on costs and benefits of resilience • Online calculator for estimating resilience value • Resilience R&D opportunities (Roadmap) with public feedback • Webinars for sharing results and soliciting feedback	1-2 years (Total: 5)
Case study and other information for codes and standards	• Select projects for case study (GSA proving grounds, forward bases, etc.) • Conduct case study • Final report • Notice of proposed rulemaking, establishment of SSPC for 90.1 resilience	1 year (Total: 6)

Lead Stakeholder(s)

NASA, DoD, USAF, Armed Services, Energy Exchange, Utilities (e.g., Southern Company, EPB, microgrid), Insurance agencies, FEMA, EPA, BOMA, ASHRAE, State/Local communities

Other Stakeholders	Role
DOE/BTO	Lead
National Labs	Lead
Other Fed. Gov.	Contribute
State/Local Gov.	Participate
Communities	Participate
Utilities	Contribute
Emergency Managers	Contribute/participate

	Builders & Manufacturers	Contribute
	Owners	Participate
	Occupants	Participate
	Academia	Contribute

Publish Advanced Energy and Resilience Design Guides (AEDRG)			QUICK WIN
Description	Add, include, and/or enhance resilience topics in existing and future AEDGs		

Desired Outcome(s)	Key Challenge(s) Addressed
Updated/more inclusive guides.	Making resilience guidance available/expected in high performance building design guidance.

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
Support from authors (DOE / NREL / ASHRAE / AIA / USGBC / IES)	NREL to initiate ASAP	1 month
Secure funding Develop / identify additional content	Need resilience benchmark (see separate Action Plan)	FY19/FY20 3 months
Update Guides	Text, graphics, technical modeling as appropriate	3 months
Publicize!	Typical conference circuit, cross promotion with partners (eblasts, social media, websites, newsletters)	beyond

Lead Stakeholder(s)

- NREL lead
- Support from ASHRAE / USGBC / AIA / IES / DOE
- Additional resilience expertise
  - NREL has in-house?

Other Stakeholders	Role
DOE/BTO	Funder
National Labs	Lead/Author
Other Fed. Gov.	Advisors
State/Local Gov.	Advisors
Communities	Advisors
Utilities	Advisors
Emergency Managers	Advisors
Builders & Manufacturers	Advisors
Owners	
Occupants	
Academia	
Other	

Create Resilience Benchmarking for Zoning & Building Codes			QUICK WIN
Description	• Clear standard / benchmarking are needed to ensure resilience goals/guidance are reflected in zoning and codes • These standards and benchmarks are dependent upon climate zone / hazard exposure / outage time		
Desired Outcome(s)		**Key Challenge(s) Addressed**	
Clear benchmarks, in a written guidance format that is widely adopted, for building codes/zoning that communities and developers can plan/finance around		• Lack of integration with energy efficiency and resilience specifically in zoning and codes • Lack of coordination among different stakeholders	

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
Funding	• Acquire funding source: DOE funded? Other entities signing on? • Define funding benchmarks	
Stakeholder Engagement	• Engage stakeholder: DOD, FEMA, AIA, ICC, councils of governments (COGs), regional planning authorities, non-profits	
Analysis • Hazard (regional) • Definition of resilience • Gap analysis of current codes	• Organize data by hazard/threat (based on most recent data!) • Analyze codes and existing work (e.g., SolSmart) that currently address threat • Define resilience • Perform gap analysis of ability of current codes to meet resilience goals	
Benchmarking Guidance (by climate specific and hazard)	• Develop new benchmarking guidance organized by climate zone and hazard	

Lead Stakeholder(s)	Other Stakeholders	Role
DOD	DOE/BTO	Project lead / Funding
DOE (Lead?)	National Labs	
FEAM	Other Fed. Gov.	Project lead / Funding
COGS	State/Local Gov.	
AIA	Communities	
ICC	Utilities/PUCs	
HUD	Emergency Managers	
Planning Authorities	Builders & Manufacturers	
NOAA	Owners	
EPA	Occupants	
Emergency planners/hazard community	Academia	
Nonprofits (USGBC)	Other	

Up the PACE	BIG IMPACT
Description	Expand the utilization of PACE (Property Assessed Clean Energy) financing to include resilience: "PACER"

Desired Outcome(s)	**Key Challenge(s) Addressed**
• Defined applicable resilience measures. • Increased participation by state • Additional financing opportunities	• Limited availability of financing for resilience measures. • "creates a backdoor"

Tasks and Milestones

Milestone(s)	**Task(s)**	**Time Frame**
Reference current research	• Draft policy paper with input from ACEEE, DOE, PACENation, NASEO	6 months
Research what states are applicable	• Verify 32 states currently applicable	6 months
Engage state legislature for modifications	• This may increase number of participating states enacting legislation due to added resilience (EE does not necessarily move the needle)	
Engage local municipalities for new/modified ordinances		

Lead Stakeholder(s)	**Other Stakeholders**	**Role**
	DOE/BTO	
	National Labs	
	Other Fed. Gov.	
	State/Local Gov.	
	Communities	
	Utilities/PUCs	
	Emergency Managers	
	Builders & Manufacturers	
	Owners	
	Occupants	
	Academia	
	Other	

Cost-Effective "DIY" Package and Solutions

BIG IMPACT

Description

- Solution applies to Residential and Commercial
- Applies to all climate zones
- Applies when the building loses power
- Opportunity to make buildings more resilient

Desired Outcome(s)	Key Challenge(s) Addressed
• Utilities will have easier time post-disaster recovery • Make homes and buildings more resilient • Benefits occupants when they lose power	• "DiY" Solutions – lack of awareness • Cost-effective solutions don't exist • Existing solutions are not widely available • Ease of integration with buildings • Package solutions don't exist • Making it safer "DiY" solution

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
• Training video • Outreach to utility	• Literature search of existing solutions • Identify missing solutions • Identify solutions for climate zones • Develop package of solutions • Develop guide & look book	24 months

Lead Stakeholder(s)

- DOE (Lead)
- Utilities
- FEMA

Other Stakeholders	Role
DOE/BTO	Funding, advocacy
National Labs	Develop the solutions
Other Fed. Gov.	DoD
State/Local Gov.	
Communities	Disaster prep
Utilities/PUCs	Incentives, outreach
Emergency Managers	FEMA outreach
Builders & Manufacturers	
Owners	Beneficiaries
Occupants	Beneficiaries
Academia	
Other	

Grid-friendly, resilient, efficient HVAC/RTU, hot water heaters, and air distribution systems	BIG IMPACT

Description

1. Development of next generation HVAC/RTU that are efficient, grid-interactive and supports resilience
2. Development of next generation hot water heaters that are efficient, grid-interactive and supports resilience.
3. Development of advanced multizone air distribution system, including air filtration system
4. Applies to residential and commercial buildings
5. New thermal design, new/advanced controls, power electronics and interconnects.

Desired Outcome(s)	Key Challenge(s) Addressed
For each technology (HVAC/TRU, hot water heaters, and air distribution systems), a new product that is: • Designed to be grid friendly • Validated via simulation • Tested/demoed in the field	• System widely not integrated with grid • Variable or tandem compressor units not widely used because they are not cost effective • Current gas appliances do not necessarily work when power is out • Turnkey solution for grid interactivity does not exist • Lack of trained workforce • Current technology may not be efficient

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
Each technology – RTUs, hot water heaters, and air distribution systems will have the following milestones: • Design • Simulation validation • Product development • Lab testing • Technology transfer • Outreach	Design, simulate, develop, lab test, demo in field, tech transfer, outreach	3-5 years

Lead Stakeholder(s)

- National Labs (DOE/DOD) – Lead
- OEM Manufacturers – Design/testing
- Academia – Modeling and R&D
- Utilities – Requirements/System integration

Other Stakeholders	Role
DOE/BTO	Funding
National Labs	Develop the solutions
Other Fed. Gov.	DOD Testing
State/Local Gov.	
Communities	
Utilities/PUCs	Help req/spec/incentivize
Emergency Managers	
~~Builders &~~ Manufacturers	Design, evaluation, tech transfer
Owners	
Occupants	
Academia	R&D
Other	

Actionable Resilience Information for American Businesses

BIG IMPACT

Description

Utilities
- IT Infrastructure
- Decision support system (business intelligence dashboard)
- Investment planning (program roll-out planning)

BTO
- AEDG for resilience
- Scout integration dimensions

Desired Outcome(s)	Key Challenge(s) Addressed
• Resilience in the built environment • Enhanced adoption (technologies, best practices within existing markets • Creation of new markets with high value jobs • Decreased impacts from disasters • Improved recovery time • Quantify improved safety, health, and non-energy benefits	• Actionability (vs irrelevance) • Integration (vs uncertainty) – people and IT systems.

Tasks and Milestones

Milestone(s)	Task(s)	Time Frame
BTO Process	• AEDG • Scout updates • Energy Plus NFP • Resilience R&D Opportunities • HITS for resilience	2 years
Implementation	• Standard compliant evaluation of resilience (90.1 compliance for resilience) • EnergyPlus and measure code submission • Web-based data hosting for resilience value	2 years (Total: 4)
Case Study	• Beta test • System feedback/improvement from CRADA/Pilot • Final Report	1 year (Total: 5)
Full Deployment	• Stakeholder communication and engagement • Process for implementing findings from feedback and A/B Testing	1 year (Total: 6)

Lead Stakeholder(s)	Other Stakeholders	Role
	DOE/BTO	Lead
	National Labs	Lead
	Other Fed. Gov.	Contribute
	State/Local Gov.	Participate
	Communities	Participate
	Utilities/PUCs	Contribute
	Emergency Managers	Contribute
	Builders & Manufacturers	Participate
	Owners	Participate
	Occupants	Participate

	Academia	Contribute
	Other	

APPENDIX A: WORKSHOP AGENDA

<table>
<tr><th colspan="2">Agenda</th></tr>
<tr><th colspan="2">Day 1 - Wednesday, June 12, 2019</th></tr>
<tr><td>8:00 – 8:30</td><td>Arrival for Badging/Full Breakfast/Coffee</td></tr>
<tr><td>8:30 – 9:30</td><td>Plenary Session
• Welcome, Introduction, and Workshop Purpose and Objectives
- Dr. Moe Khaleel, Associate Laboratory Director for Energy and Environmental Sciences, Oak Ridge National Laboratory
• Efficiency, Flexibility, and Resilience – Connections and Opportunities
- Dr. Karma Sawyer, Program Manager, Building Technologies Office, U.S. Department of Energy
• Resilience in Practice
- Laurie Schoemann, Senior National Program Director, Resilience and Disaster Recovery, Enterprise Community Partners
• Overview of Facilitated Discussions
- Matt Antes, Energetics</td></tr>
<tr><td>9:30 – 9:45</td><td>Break
• Proceed to Breakout Rooms [Enclosures and Building Operations]</td></tr>
<tr><td>9:45 – 11:00</td><td>Breakout Session 1
• Instructions and introductions
• Opening discussion – Examples of efficient, flexible, resilient technologies and systems
• Facilitated discussion – Resilience risk factors
What 'resilience risk factors' should be of concern before, during, and after an event?</td></tr>
<tr><td>11:00 – 12:00</td><td>Breakout Session 2
• Facilitated discussion – Understanding nexus between buildings and resilience
How do energy efficient/load flexibility technologies and practices in buildings positively or negatively affect resilience?</td></tr>
<tr><td>12:00 – 1:00</td><td>Lunch
• Anecdotes of Success Integrating Resilience in Buildings as a part of Planning, Construction, and Post-Event Rebuild. Resilience experts share anecdotal examples of actual projects that have had measurable impact.
- Nikhil Nadkarni, Cambridge Community Development
- Jeremy Williams, Building Technologies Office, U.S. Department of Energy
- Michael Walton, Greenspaces Chattanooga</td></tr>
<tr><td>1:00 – 1:45</td><td>Breakout Session 2 (continued)
• Facilitated discussion – Understanding nexus between buildings and resilience
What resilience technologies and best practices in buildings are necessary to address resilience risk factors, but currently uncorrelated to energy efficiency or load flexibility?</td></tr>
<tr><td>1:45 – 2:45</td><td>Breakout Session 3
• Facilitated discussion – Challenges and Opportunities
What are the challenges that must be addressed to increase the market uptake for buildings that fully integrate energy efficiency/load flexibility with resilience?
Which challenges present the greatest barrier to increasing the market for buildings that fully integrate efficiency/flexibility and resilience?</td></tr>
<tr><td>2:45 – 3:00</td><td>Break</td></tr>
</table>

3:00 – 4:30	**Breakout Session 3 (continued)** • **Facilitated discussion – Challenges and Opportunities** *Which opportunities offer the greatest potential impact for fully integrating efficiency/load flexibility with resilience?*
4:30 – 5:00	**Plenary Session** • **Report-outs from breakout groups** • **Q&A**
5:00	**Adjourn Day 1**
Day 2 - Thursday, June 13, 2019	
8:00 – 8:30	**Arrival/Full Breakfast/Coffee**
8:30 – 10:15	**Breakout Session 4** • **Review of key challenges and opportunities from Day 1** • **Plan for Day 2** • **Small Group Exercise – Action planning** *What actions should be taken to better integrate energy efficiency/load flexibility technologies and resilience in buildings?*
10:15 – 10:30	**Break**
10:15 – 11:15	**Breakout Session 4 (continued)** • **Small Group Exercise – Action planning (continued)** *What are the opportunities for coordination among agencies, organization, other stakeholders?*
11:15 – 12:00	**Plenary Session** • **Report-outs from breakout groups** • **Next steps**
12:00	**Adjourn**

APPENDIX B: PARTICIPANTS

BREAKOUT GROUP 1: ENCLOSURES

Name	Affiliation
Rick Bender	KY Office of Energy Policy
Brian Blackmon	City of Knoxville
Darryl Boyce	ASHRAE
Kathleen Bryan	City & County of San Francisco
William Bryan	Southeast Energy Efficiency Alliance
Ryan Colker	International Code Council
Bart Enright	ComEd
Arathi Gowda	SOM/Architect
Adam Hasz	DOE - BTO
Christine Herbert	SPEER
Justin Hill	Southern Company
Terry Hill	Passive House Institute
Brooke Holleman	DOE - OWIP
Achilles Karagiozis	NREL
Marc Lafrance	DOE - BTO
Kate Lee	Southeast Energy Efficiency Alliance
Emily Lorenz	PCI
Craig Messmer	Unico; ventilation
Scott Morgan*	Energetics
Sven Mumme	DOE - BTO
Nikhil Nadkarni	Cambridge Community Development Department
Sam Rashkin	DOE - BTO
Michael Reiner	WIP (Fellow)
David Roberts	NREL
Bipin Shah	WinBuild, Inc
Rodney Sobin	National Association of State Energy Officials
Kaiyu Sun	LBNL
Jeremy Williams	DOE – BTO

* Facilitator

BREAKOUT GROUP 2: OPERATIONS

Name	Affiliation
Matt Antes*	Energetics
Heather Buckberry	ORNL
Greg Dierkers	DOE
Erin Gill	City of Knoxville
Heather Goetsch	DOE - BTO
Diana Hun	ORNL
Srinivas Katipamula	PNNL
Teja Kuruganti	ORNL
Steven LaBarge	ComEd
Luke Leung	SOM/Architect
Andrea Mammoli	Univ. of New Mexico
Paul Mathew	LBNL
Ayyoub Momen	ORNL
Jeff Morrow	Lendlease
Joshua New	ORNL
Christopher Niebylski	PNNL
Ron Ott**	ORNL
Aaron C. Petri	USACE
Hung Pham	Emerson
Stacey Rothgeb	NREL
John Sarter	Clean Coalition
Karma Sawyer	DOE - BTO
Laurie Shoeman	Enterprise Community
Michael Specian	DOE - BTO
Chuck Thomas	EPRI
Elaine Ulrich	SETO
Michael Walton	Green Spaces
Max Wei	LBNL

*Facilitator
**Host/organizer

APPENDIX C: RAW RESULTS

BREAKOUT SESSION 1

EXAMPLES OF EFFICIENT, FLEXIBLE, RESILIENT TECHNOLOGIES AND SYSTEMS

Think of one example of a flexible or energy efficient building technology or system whose operation can make it easier for occupants, owners, utilities, communities, or any other group to withstand or rapidly recover from a major disruption.

Group 1: Enclosures	Group 2: Operations

• HVAC raised above the structure for flooding
• Flooding event: Building envelopes designed with fast drying capabilities, without compromising EE & resulting comfort.
• Move to an all DC city block microgrid structure for resilient grid. On block, all passive house/zero ready structures with PV, storage, and DC appliances. One connection with main grid from city block. Include blockchain
• Duel fuel appliances
• Controls + Communications: Back-up power/generation for essential systems. Redundant communications for BAS
• Demand response to curtail usage during event. Loss of generation on grid-load shed
• Cool reflective paint envelope roof + walls
• Green or blue roof (for high rainfall storm events)
• Next gen attics – Above deck ventilation, insulation, radiant barriers and cool roof – 90% lower peak load (service heat [no energy])
• Wind/water intrusion: No attic ventilation – temporary or not
• Effective Window to wall design ratio based on risk at location
• Overhangs with integrated PV
• Passive solar homes (natural heating, cooling, lighting, fresh air, control)
• Good old-fashioned pre-industrial climate-responsive design. (Respond to extreme heat/cold and power outage)
• Thermal mass of buildings
  ○ Both w/ and without power
  ○ Form of thermal storage and temperature logging for loads
• Thermal storage and minimal power supply (e.g., backup generator, PV, CHP)
• Batteries/Electric storage
	DERs
	• Distributed low-energy wastewater treatment:
	  ○ Treat waste
	  ○ Generate fuels for energy generation
	• Onsite renewable hybrid inverter battery backup: charge controller for critical load
	• Portable shipping container size batteries that can be delivered to a PV building when the grid is down. Low-cost solution because it can be shared, made available where/when needed
	• Quick-connect panels for mobile power and district energy "ports" for mobile boilers/chillers
	• CHP system built to load (3D printed)
	• Gas or diesel generator; indoor kerosene heater ($139)
	
	Communities Critical Facilities
	• Community Solar "charging" station-charge devices, run medical equipment, refrigeration, access to communications. Day-to-day function for public.
	
	Design
	• Passive
	• HQ insulation (installed correctly): moderate temperature fluctuations.
	• ABC to enable Rapid Recovery: best opportunity to rebuild better, but decisions need to be made fast.
	  ○ Modular water/power supply
	  ○ Modular permanent housing
	
	Construction Equipment
	• Cross laminated timber structures: projectile resilient, blast performance, thermal mass
	• Self-powered AC (packaged w/ storage or DERs)

- Provide some backup
- Enable RE(PU) (solar + storage)
- Allow load management
- Reduce stress to grid (lower peaks, ramp-rate) (cost savings too)
- Power quality benefit

- Power outage: Energy storage with solar panel window panes
- Solar shingles -> Incorporate solar generation into building design/components
- Back-up generators (portable or not)
  - Assumes no power scenario
  - Manual start or auto-on systems
  - Could be as simple as a wood stove (rural)
- Operable windows
- EE/withstand: Increased levels of insulation. Provides habitable, shelter-in-place during event. Also enhances flexibility if augmented with other systems (e.g., pre-cooling)
- Increased/effective insulation to support passive survivability (without power) and/or reduce impact/energy use/grid stress in extreme heat/cold. Rigid insulation may also provide structural strength.
- Highly insulating dynamic windows—thin triple/VIG-dynamic glass/shades (severe cold/heat [no energy])
- Ventilation/operable for 72 hours passive survivability / in high rises. Associated pressurization issues -> Move to certain mid-rise floors. Events: Extreme heat, flooding
- Tunable or variable/dynamic technology that connects indoors to outdoors when outdoor conditions are favorable and disconnect when not favorable.
- Flexible ventilation (good for heat wave, blackout, wildfire)
- Quick install, EE windows (ventilation rating, dynamic/PV) Exterior attachments. Cool Envelope, reflective paints
- For power outage: operable windows with shutters
- For general disruptions: education/leadership and code enforcement
- FEMA safe room / multipurpose FEMA shelter
- Enclosure-roof stability and insulation are important in wind/water events – once the roof is lost, all is lost. No ability to shelter in place; insulation allows safety from extreme temps.
- ICF-insulated concrete forms: Building is weather, fire, and earthquake resistant. Highly energy efficient
- Storm-proof windows (or shutters). How? Withstands (certified) hurricane wind driven debris, EE opportunity: Add insulation or SHGC
- Integrate HVAC and storage and renewable generation with advanced controls → similar to a hybrid car. Gas detection and ventilation in conjunction with controls (HVAC). Moisture and water detection. Lots of sensors.
- Thermal storage and envelope integrated near coupled with dynamic insulation of activation system to provide dynamic heat transfer for occupant comfort/reduce cold fluctuations.

Sensing, Analytics, Controls

- Indoor Air Quality Sensor to respond if Air Quality degrades to alert resident or building operator to close windows or activate building air filter for smoke/wildfire/air pollution.
- Dynamic occupant communications platform with instructions, needs, etc. → Real time status/to-dos (Nest thermostat on steroids)
- Software technology: Emerging rationing of power under constrained availability to extend critical operations in buildings
- Microgrid load controller:
  - When main grid is down, identify available power (renewable or onsite generation) and control schemes to ensure power is delivered to critical loads.
- Pending storm warning Event (Level x):
  - Storm approaches service territory
  - Distribution operator determines level resilience
  - Pending storm warning event sent to DERs (loads and generators)
  - DERs use information to prepare and protect itself and humans
- Early add-on retrofits with resilient back up power and energy storage to predict/withstand power outage and recover for a longer period in reduced mode.

• 2x6 construction in residential buildings.	

ADDITIONAL RESILIENCE RISK FACTORS

What 'resilience risk factors' should be of concern before, during, and after an event?

Draft Resilience Risk Factors

Building Structure Risk Factors

- Projectile Impact Resistance
- Wind Load Resistance
- Structural Lateral Force Resistance
- Structural Dead Load Resistance
- Ice Dam Resistance
- Adequate Height Above Grade
- Fire Resistance
- Pest Resistance
- Water Resistant Structure
- Bulk Moisture Resistance
- Erosion Resistance
- Recovery of building infrastructure following an adverse event

Building Operations Risk Factors

- Inability to pump water to high floors
- Compromised ventilation/reduced air quality including from occupant activity (e.g. lighting fires, improper generator use, grills)
- Thermal survivability during extreme heat/cold events
- Lack of lighting
- Lack of containment on hazardous materials
- Compromised building management systems or other digital controls (e.g., due to cyberattack)
- Loss of a fuel source (electricity, natural gas, solar, storage, etc.)
- Inability for grid to provide reliable power

Continuity of Business Operations Risk Factors

- Softer fails and restarts of mechanical equipment
- Loss of revenue and other business-interruption costs to businesses whose property is compromised
- Inability for businesses to provide critical services
- Compromised waste collection, sewage disposal, or other sanitation issues
- Inability for emergency shelters, schools, fire stations, hospitals or other critical facilities to provide critical services
- Food/medicine spoilage
- Medical equipment outages
- Loss of commercial inventory if goods processing is time sensitive

Community/Systemic Risk Factors

- Anxiety, stress, trauma, and PTSD
- Costs associated with grid black starts
- Economic losses within the broader community
- Looting
- Access to clean drinking water
- Transporting and sheltering costs for displaced households and pets
- Insurance costs other than insurance claims
- Costs for urban search and rescue

Additional Resilience Risk Factors

Group 1: Enclosures	Group 2: Operations
• Potable water supply should include pump stations • Request: Rank these challenges later • Change "looting" to "security" • Group several challenges under "loss of power" • Community category: Loss of health and high energy burden • Cross-over for structural + operations risks • Risk of losing population after an event: displacement • Scenario analysis during building design • Equipment failure, generally	• Behavioral factor • Access to information • Vulnerability metrics • Air pressure (e.g., hurricanes → doors) • Chemical, radiation • Training/Drills • Repurposing/interoperability of devices • Fix term. Housing • Black-start with bd equipment • More plug and play components. • Community cohesion. • Climate risk → action • Maintenance of systems over time, cost consideration there. • Real exercises to test • Lack of knowledge of human behavior, human tolerance issues. • Simulations for impact on buildings • Community response/recharacterization. Will people leave? • Thermal shelter in place policy • Resilience = value = gentrification = lack of community • Community/business reputation

BREAKOUT SESSION 2

UNDERSTANDING NEXUS BETWEEN BUILDINGS AND RESILIENCE

How do energy efficient/load flexibility technologies and practices in buildings positively or negatively affect resilience?

What resilience technologies and best practices in buildings are necessary to address resilience risk factors, but currently uncorrelated to energy efficiency or load flexibility?

Group 1: Enclosures

Area	Complement	Conflict	Currently Uncorrelated (Additive)
Attics	• Unvented attic [fire, wind] • Next generation attics • Vented attic [severe winter weather]	• Unvented Attic [Severe winter weather] • Vented attic [wind, fire]	

Insulation / Envelope Seal	• High R-value insulation; risk -> thermal survivability
	• Increased insulation levels enhance efficiency and thermal survivability during extreme heat/cold events
	• Air seal especially for cold weather climes maintains temp
		• Thermal survivability and IAQ in extreme heat may conflict with tight building envelope
		• Increased sealing of envelope can increase risk to moisture build-up within building
		• Low infiltration rates/use of Energy Recovery Ventilator (ERV)
		  ○ When power goes down, no/low ventilation is available
		  ○ Also maintenance
		• Infiltration/sealing [heat wave and power outage, wildfire]
		• Efficient walls (fewer windows, tighter construction) [ventilation, loss of power, thermal stress, codes, security]	

Windows	• Reduced window to wall ratio (non-open): projectile impact, wind resistance • Window film: Anti-shatter; reduce heat gain • Improved windows = less vulnerability to flying debris (wind) or wildfire: films; triple pane • Windows wall: thermal comfort, day lighting, ventilation (controlled)	• Large openable windows: projectiles, water resistance, wind • Highly insulating windows – keeps cold out during winter but heat in during summer with power loss. (need operable) • Structural strength. Thermal shorts. Operability • Operable windows/natural ventilation [smoke from wildfires]	• Impact-rated/impact resistant windows

Area	Complement	Conflict	Currently Uncorrelated (Additive)
		• Flammability of certain insulation. Also cladding • Some of higher R-value insulation; Risk → fire resistance • Increased insulation levels may hamper recovery of building infrastructure following adverse event – e.g., flooding, drying	
Structural / Framing / Construction and Installation Practices	• Rigid insulation; wind/projectile resistance (more data?) • Increased attic insulation (that intentionally adds to structural integrity) improves energy-efficiency and risk of wind damage. • Concrete wall systems [insulated concrete forms (ICF), ICP, precast] [wind, fire, floods, impact, pests]	• Advanced wall framing [fire, flood, impact, pests] • Shading overhang [wind]	• Building materials with low global warming potential (direct/indirect) • Off-site construction as post-disaster recovery strategy with integrated efficiency • Steel fasteners to attach exterior insulation. Good for structure, but bad for thermal building • Windows/walls interface: air leak, water leakage, etc. Energy loss • Use screws instead of nails (in wind prone areas) reinforced closet for saferoom • Impact resistant assemblies [hurricane, tornado, hail]

Microgrids	• City block DC microgrids:
	  ○ AC Grid improved reliability
	  ○ Improved fuel poverty, demand response, transportation expenses, healthy homes, solar flare protection
		• City block DC Microgrids: availability of DC appliances and management software [fire, cyber vulnerability]	

DERs/Grid Integration + Storage	• PV integrated wall systems [electricity] • On-site generation. Ex: solar + storage. Demand management and avoids lost power from bulk disruptions • Electric backup/microgrid and/or storage: supports all electric powered functions – space conditioning; water pumping; refrigeration; medical equipment; etc. • Storage/generator [loss of power] [efficiency]	• PV integrated wall systems [wind, moisture management] • Solar PV wiring and inverters for islanding and grid services. • Solar PV attachments • Demand response: costs associated with grid black starts. Provide opportunity to adjust and control loads (add resistive loads) to control frequency/PF • High level of renewables/load masking: inability for grid to provide reliable power.	

Area	Complement	Conflict	Currently Uncorrelated (Additive)
	• Structure with high thermal mass usually resists projectiles, wind, structural dead load.	Need policy to adapt and allow utilities to deploy new tech • Concern of Li-ion batteries as fire hazard	
Sensors and Controls		• Increased reliance on sensors/control for EE, but increased vulnerability to a cyber attack • Complexity of controls when restarting after disruption	
Other	• LED lighting: lower energy use intensity, need less energy; more lighting in critical load. • Retrofit building with heat pumps (with elevated electrical panels). Address efficiency and floodable basement heating systems	• Oversized HVAC: Excess power consumption • Higher cost/longer rebuilding time [all hazards] • White roof [Heat wave, power outage] • Structural insulation/improvement: higher embodied carbon than wood frame → consider timber with concrete lateral (unless fire)	
Seismic			• Earthquake resistant construction in earthquake zone [lateral loads] • Seismic reinforcement – opportunities to integrate EE elements • Strengthened structure for earthquake
Flooding / Stormwater Management			• Stormwater management practices/structures/landscapes, including some low-impact development (permeable pavement, etc.) BUT could favor EE by reducing heat island evapotranspiration • Plantings, blue roof, permeable paving • The location of mechanical and electrical equipment on higher levels • Blue/green infrastructure to reduce/eliminate grey infrastructure. For example: Sponge landscape, green roof to reduce flooding. Most effective at community scale. • Raise home above flood elevation [flood]

Area	Complement	Conflict	Currently Uncorrelated (Additive)
Fire			• Fire/hail resistant roofing • Fire resistance materials • Sprinkler systems • Non-combustible materials [fire] • Fire resistant roofing, cladding. Fire detection and suppression systems. CO detectors • Spark arrest in outside air filters in fire prone areas. Cleanable filters? Also easy to maintain ERV
Wind			• Safe rooms or shelter from tornadoes. Thermal coding room? Passive cross ventilation? • Exterior security/hurricane roller shutters – EE too. New AERC ratings soon. • Storm shutters [wind, impact] • Wind resistant roofing [wind] • Air gap at unvented attic roof [severe winter weather]
Electric System			• Electrified cooking appliances • Ensure RF connectivity throughout building. Future connected smart devices/lighting • Separate circuits for back-up power to critical loads.

Group 2: Operations

Area	Complement	Conflict	Currently Uncorrelated (Additive)
Intelligent Functionality & Controls	• Energy conservation measures (ECMs) can subsidize more expensive resilience measures under certain contract types. • Grid interactive buildings control architecture: ○ Complement: Independent of "IoT" cloud applications—operates local mode • Efficient components: Advanced controls enable setbacks and other resilience strategies • Advanced and resilient building controls: complements improved energy efficiency continuously that also support resilience, post-event • Utility scale dynamic microgridding (intelliruptors) can keep critical facilities powered or stagger power availability • Sensors allow co-optimization for EE/DF or resilience • Low-VOC comp. of home vs. durability. • SaaS optimization of buildings with storage could predict resilience related events. • HVAC&R: Separating sensible and latent loads	• More reliance on electricity conflicts with power outage resilience – need multi-fuel source hybrid • Water filtration systems. Rain barrels, etc. ○ Operation during a blackout ○ Use renewable generation ○ Low cost, easy to use • Grid interactive buildings control architecture: ○ Conflict: Dependent on IoT and cloud applications • Efficient components: IoT and advanced building controls are dependent on wireless communication. Significant loss of functionality during outages. • Utility/grid connected solar doesn't always provide back-up power (interconnection agreements create resilience conflict) • Ability of EV, solar PV, home automation, HVAC to integrate during an event. Interoperability needed like USB, DC port. May increase cost • Smart power façade • Cybersecurity • Smart home devices (lighting, etc.) • ECMs can reduce loading on generators below low-run thresholds • Embodied energy in manufacturing of car batteries and energy loss in batteries.	• Auxiliary / Backup generators • Energy assurance plans/exercises • Diesel • Continuity of operations plans • Cybersecurity
HVAC&R	• Increased insulation for refrigeration	• HVAC: Ice storage to help ride through an event while also making day-to-day operations more cost-effective	• ASHRAE – Resilience capital needs
Storage	• EVs = Storage • V2B (vehicle to buildings) technology + mass community adoption + solar: solves all building operations risks; ability to move energy infrastructure out of harm's way; enables sharing of energy (mobile microgrid); increase transportation energy; value stacking	• Thermal energy storage (i.e., water heaters, operating @ 140 deg vs 120 deg F)	

Area	Complement	Conflict	Currently Uncorrelated (Additive)

DERs + Gas	• Generally, distribution of assets is good
	• DC Power: direct tie to PV, low load, and island-able
	• Natural gas technologies can help resilience and energy efficiency for heating applications
	• CHP
		• Fuel switching (gas) = resilient, but gas has CO2
		• Fuel, Diesel, Gas. Life cycle.
		  ○ Operations – over venting
		  ○ inefficient pumps.
		  ○ Geothermal-hydropower	

"Markets" Opportunity	• Mass timber (cross laminated timber [CLT]) complements resilience of buildings and forests • Unmanaged MELs and associated waste heat (lots of small loads add up) (pre/post event)	• Mostly conflicting because round trip efficiency < 100% and energy required for manufacturing • Local materials can decrease supply chain constraints for recovery	• Insurance/appraisals • Energy efficiency definition can be complicated • Defining value of resilience V.O.R. • Decarbonization
Envelope and Ventilation	• Building envelope/air sealing → complements mold/moisture reduction and indoor air quality. • Vernacular design and architectures measures, style to alter community resilience and historicity of comm. • Passive house methodology: 80% improved thermal efficiency, improved IAQ, improved acoustics, improves strength and durability.	• Reduced infiltration can worsen thermal conditions • High R, but flammable insulation (during event) • Mechanical ventilation: complement for general IAQ (indoor air quality??) but conflict during smoke/fires as it could worsen IAQ (Berkeley example) • Air sealing: Conflict in Miami example. Complement in in cold regions/during winters/outages • Passive house methodology: Heat recovery ventilators (HRV) need uninterruptible power supply (UPS) (to improve IAQ) and increases costs slightly	
Communities	• Community behavior, sharing economy, community resilience		• Zoning/land use planning • Emergency shelter/preparedness locations by communities • HUD CDBG-DR (community development block grants disaster recovery program) has green standards but no resilience standard • FEMA Hazard Mitigation Grant Program • Military operations or exercises
Construction	• Strength in high-performance/quality: High performance buildings have higher quality materials, buried utilities. PV panels more resilient to hail than roof (NREL: Only 1 of 100s damaged)		• Siting of equipment/facilities (e.g., elevation: ground source vs. on the roof) • Earthquake retrofits. Retrofitting older buildings – if the walls are open already – why not make them energy efficient?

Area	Complement	Conflict	Currently Uncorrelated (Additive)
			• Hardening: upgrades to the exterior façade for impact protection • Not including energy efficiency upgrades when retrofitting for resilience (pest control)
Utilities	•	• Utilities have different needs • DR/pre-cooling: detracts from energy efficiency but promotes resilience/resilient systems. • Spatially and temporally matching solar PV and HVAC usage – Improved resilience but may conflict efficiency. • HVAC → must run with solar so generation < (1) Load • Utility franchise rights may make transactions between buildings difficult. Need microgrid/grid guidelines for resilience.	• Load (heating/cooling) profile in a district • Microgrids • Solar flexibility/curtailment: overbuilding is cheaper than adding storage • N + 1
Water Management	•	•	• Rainwater collection and wastewater management • Clean water resilience has no energy efficiency content

BREAKOUT SESSION 3

CHALLENGES

What are the challenges that must be addressed to increase the market uptake for buildings that fully integrate energy efficiency/load flexibility with resilience?

Which challenges present the greatest barrier to increasing the market for buildings that fully integrate efficiency/flexibility and resilience?

Group 1: Enclosures

Cost/Benefits

- Cost-benefit analysis: How do EE measures avoid losses?
- Exploring complement: uncertainty. Re Benefit and cost savings associated with resilience-related aspects of tech. Example: What cost savings of shelter-in-place vs evacuation/relocation? How would including this affect cost-effectiveness of EE/LF measures?
- How to properly value resilience for economic analysis.
- Cost higher
- Insurance price everywhere that rewards risk reduction
- Reducing value in transaction (appraisal, mortgage rate, insurance)

- Need models/analyses of EE/Load Flex benefits – demonstrate value, impact. -E.g., Florida nursing home tragedy noted this AM
- Economic – EE long-term investment – resilience only for the possibility of unknown reality. Limited time
- Real and/or perceived value (vs cost). What value is there beyond EE and resilience?
- Financial: Energy improvements can be evaluated on a clear business case, but resilience does not have well defined payback
- Mutually agreed cost benefit methodologies that allow effective decision making. +across industry
- Technical cost:
  - It's infrastructure cost $$$.
  - It's a building cost $
  - Pass the buck cost.
- Split benefits—up front cost vs operational risks/costs
- Metrics for quantification. Trade-offs are inevitable, but don't have clear metrics to evaluate the trade-off.
- Monetize all factors, benefits (e.g., human lives)
- Lack of backing up resilience warranties
- Valuation: resilience impacts, cost-benefit, metrics and methods can add to value. Hazard specific factors detract (e.g., wind/snow loads, fire venting, grid flexibility, etc.)

Siloes

- Program, policy, funding, etc. operate in siloes.
- Siloed nature of building industry across design/construction/operation, efficiency/resilience, disciplines, codes/policies/agencies, advocacy, manufacturing. No one working toward parallel/complementary goals.
- Siloes between energy stakeholders and disaster planning/recovery officials.
- EE stakeholders don't really think about resilience and vice versa
- Different agencies at state, federal, local level that often don't coordinate/communicate: DOE, FEMA, HUD, EPA, USGS, NIST

Planning and Priorities

- Time/money/lack of planning
- Lack of clear priorities by hazard type/severity level, building types/uses, critical technologies/loads, key mitigation strategies
- Uncertainty of granular impacts of climate change to:
  - inform simulation, design, sizing
  - codes being far below climate impacts (say you can convince client 5% cost premium by market/program)
  - leads to designs that are less resilient/load flexible for energy, wind, and water.
- Uncertainties
- Clear metrics on LF and resilience
- Problem is too broad. Need some prioritization/optimization/consolidation based on risks to be tackled.
- Market segmentation
- Priority post event when focus on just shelter

Policies

- Policy/codes standards: Broad scale implementation will struggle without higher floor requirement
- Code adoption: State building code adoption frameworks (e.g., Home Rule or Dillon's Rule) and updated processes (e.g., picking amongst various codes) – results in inconsistency and conflict
- Aligning incentives with risks

Grid

- Enabling utilities to own storage for variety of purposes (frequency response, voltage smoothing) and monitoring/controlling customer generation – policy change.
- Natural gas → heat pump for EE/decarb + load flexibility but adding A/C for some increasing usage/grid load.
- Demand response – weather impact grid. Peaks – load shifting. Grid resilience – education, customer awareness, auto-response.
- Increasing cost of electricity: decarbonization vs affordability
- Allowing solar to power home during supply outage.

Lack of Education and Awareness

- Changing the mindset of designers, contractors, owners (commercial and residential)
- Lack of building science skills and integrated design of buildings including potential role of microgrids
- Education – Why? Training – How? Momentum – change is difficult
- Consumer/stakeholders lack of understanding. Lot of confusion hinders buy-in
- Lack of awareness/perceived need from building owners (retrofit) (depends on impact)
- Integration in professional degree curriculum
- Workforce skills
- What is resilience? Simple definition for common understanding

Modeling tools

- Performance verification: whole building approach and optimization difficult and … take very long for update. E.g., start small and build up from there?
- Integrating modeling tools for design decision making. Real-time/near real-time energy, BIM, seismic/structural, weather file integration.
- Incorporate occupant behavior in resilience modeling
- Standards, methods, and tools to evaluate resilience:
  - Grid resilience models with interaction of buildings
  - Water flooding/wetting/drying of structures
  - Structure predictive capabilities
  - Climate loading predictive capability
  - Techno-economic analysis for resilience measures

Research Gaps

- Need low-carbon concrete binders (non-Portland cement) that are technically similar and scalable. Embodied carbon in concrete binders negates benefits.
- Retrofit existing structures for extreme events + EE with no knowledge of design loads and assumptions.

Group 2: Operations

Building Complexity and Design Challenges

- Building complexity (HVAC) and controls complexity = Big Challenge
- Ground-up reimagining?
- Materials
- Integrated simulations
- Fire and electricity generation/storage
- Ancient technology for retrofitting buildings

Energy "Routing"

- Electricity distribution systems in buildings don't segregate loads from critical loads, which is a challenge for resilient operations.
- Can't maximize site/share solar in many AHJ's/utility territories. Franchise rights, net metering, and virtual net metering (VNEM) restrictions.
- An energy routing mechanism in a building to integrate generation, consumption, and storage – improve resilience and efficiency

Collaboration

- Resilience investments tend toward less "risky" options ≠ innovation
- Resilience framing often focused on acute events, not chronic stresses
- Silos separating groups and hindering collaboration/different values
  - Utility
  - Community
  - Organizations
- Funding: Silos; one bucket; EE, grid modernization, and resilience [all separate and trendy in different years, so funding is inconsistent and uneven]
- Incumbent industries primarily petrochemicals: lack of willingness to transition.
- Utility policies/options not promoting an integrated approach
- Training/Education jurisdictions: include energy efficiency in audits.
- We might miss conflicts between energy efficiency and resilience when advancing one or the other.
- Generational differences
- Transmission access charges → Transactive access charges
- Insufficient focus on vulnerable communities → inequality

Knowledge and Awareness

- National policy and variation thereof (vacillation)
- Awareness knowledge/information
- Making EE/LF relevant to overall organizational strategy/KPIs/Story
- Master planning/Sync/platform
- Argument/framing for energy efficiency policies – Enunciation of decision-makers.
- No method for users to see if they are in area or their building is vulnerable to enable investment interest until it happens
- Lack of knowledge of situational vulnerability
- How does population density impact resilience?
- Workforce development

Cost

- Cost: not valued enough to pay for
- O&M (cost, staffing, complexity)
- Manufacturers to go extra mile to incorporate resilience into their equipment.
- Workforce training & education
- Money isn't available.

Valuation Measurement Monetization/ROI

- Standard methodology for valuing resilience
- Resilience metrics definition/standardization
- Quantifying accurate and significant ROI to motivate change from business as usual
- Linking value of resilience improvements to specific, actionable steps/energy efficiency measures
- Identifying: (a) ROI for investment; (b) true risk communication → modeling
- Design/construction often paid by different $ than operations; hard to value resilience; value engineering.
- Are district-systems (etc.) more resilient?
- Resilience metric? Sky is the limit on how resilient you should be.
- Valuation of EE/LF for resilience dollars.

Miscellaneous

- Voiding contracts and warranties
- Low-income program focused on crisis bill repayment vs. investment/weatherization, many restrictions.
- Logic model: multi-office communication or coordination
- Split incentives: Renter/landlord LLC
- Support of codes for resilience because life safety. Energy efficiency codes viewed as luxury.
- Building data/management [B/D, operations]
- Building systems & appliance are designed for efficiency, but rarely do they design them from a resilience perspective.

OPPORTUNITIES

Which opportunities offer the greatest potential impact for fully integrating efficiency/load flexibility with resilience?

Group 1: Enclosures

Participants votes on categories as the "Big Impact" areas. Final tallies in parentheses.

Rating Systems (11)

- Consumer demand: MLS to include resilience rating "A" through "F"
  - No one wants a grade "F" home/building
- Introduce symbolic rating system for buildings for fire, wind, water, earthquake, etc.
- Align research with 3rd party standard strategies for biggest market impact. More buying power → faster resilience. Reli, FORTIFIED, Enterprise
- Establish metrics by (see valuation card from challenges exercise). Continued stakeholder workshops. Pilot analysis/studies to establish boundaries (sensitivity)
- Residential market: lowest cost/square foot, biggest investment. Messaging clarity – A building is like a car, people don't know what they are buying.

Codes (11)

- Hazard based energy efficiency + resilience codes (Fortified+) and standards.
- Policy: Crafting proposed changes as additions to/in format of code suites to ease/guide adoption in more communities. [standards, policy]. Coordinated overlay code
- Advocate for energy code as recognized "hazard-resistant code" in FEMA implementation of DRRA.
- Weather shift tools shared with industry for multiple emissions scenarios and A.R. reports from IPCC. Mandated by code like CIBSE for 2020, 2050, 2080.
- Interagency/intra-agency code working group.

Value Proposition/Business Case (9)

- Big impacts: Insurance industry properly values and prices resilience risks and premia
- Financing for resilience retrofits using energy savings (think ESPCs, but instead to finance resilience retrofits, or vice versa)
- Define value proposition that resonates with Developers and Home owners. (n.b., this is probably not cost-benefits analysis results)
- Know target for cost. Calculate insurance discount for positive cash-flow for resilience (like it is for efficiency)
- USA retrofit strategy will include resilience elements. We will be the last country but end up the best
- Begin conducting techno-economic analysis of EE/LF technologies incorporating estimated savings stemming from resilience.

Collaboration (8)

- Develop collaboration teams to break down silos (Federal and State level) to align various codes and adoption cycles.
- Collaboration with resilience stakeholders to co-brand and co-market Energy Efficiency/Resilience (i.e., weather forecasting, mortgage co, insurance co, appraisers; ISO: first responders, etc.)
- DOE/EERE participation on FEMA/NIST post disaster assessments.

Education (8)

- Education and outreach to regulators and policy makers (with pilots to demonstrate); to homeowners (rating system to draw adoption); construction workers

- Awareness: Proliferation/packaging of compendium of existing knowledge (specifically geared for mass/lay consumption) e.g., Better Buildings SWAP.
- Including energy efficiency in homeowner's/building resilience handbooks
- Education: create design guides for various types of buildings to describe safe, energy efficient, resilient building design
- New professional society on resilient communities – interdisciplinary certifications, education, degrees.
- Instead of Harvard Business Cases, Resilience and Energy Efficiency business cases
- Create a good, better, best resilience and energy efficiency website to explain the different technologies. (note the energy efficiency side may exist from utilities or other stakeholders)
- Take studies to demo EE/LF-Resilience linkage and assemble together emergency management, insurance communities, energy communities to raise awareness (take study results to the people that need to see them)
- Leveraging disaster prep/harnessing people's attention (ex., getting people to buy storage instead of generators)
- Development of talking points to explain benefits of resilience and energy efficiency integration (quick win)
- Integrate information about resilience with climate change education and outreach

Studies and Tools (7)

- Standardization/quantification of social impacts to help frame cost/benefit of resilience.
- Studies to demonstrate EE/LF-resilience linkages (e.g., polar vortex impact under hi/lo energy efficiency scenarios; how long facility operates under limited backup and fuel; how long buildings habituate without power)
- Support energy module for NIBS mitigation saves study which is widely accepted within resilience community. Provides consistency in cost-benefit.
- Code study: Study of various E. Codes (+ editions) and how they translate E, Resilience (nexus) and shelter-in-place capability following a grid power outage event. Add resilience measures to ongoing work (field studies)?
- Create preliminary metrics that evolve with better understanding of changing (climate) conditions.
- Simple tools to quantify and assess resilience (quick wins)
- Empirical evidence: document case studies of "single building standing" and best practices that worked.
- Decision making tools considering both energy efficiency and resilience quantitatively (long term)

Grid (4)

- Utility transparency in grid planning to encourage DERs including energy efficiency: flexible generation, flexible load → Grid resilience
- Leverage existing assets: engage utilities/EPRI on standard switching for PV to power home during outage.
- Leverage existing assets: Optimize PV, battery storage and EV battery for resilience solutions.

Pilot projects (4)

- At the city block level: N number of passive homes with PV, storage, and DC appliances, all linked/aggregated via DC microgrid. Benefits include: 50% energy for cooling, 90% for heating, 40% plug loads; ancillary services to big grid, transportation
- Pilot programs with homeowners and insurers
- Pilot demonstration project to demonstrate energy efficiency & resilience in each qualified zone (fire, hurricane, etc.). Collect data and publish analysis, including cost and ROI. Consider dynamic energy efficient windows, cool reflective paints, advanced insulation, solar ready home equipment to demonstrate potential.

Workforce Training (4)

- Builder and contractor education workshops on impacts and resilience measures
- Targeted local training: Stafford act will provide funds – A component of that should be local training
- Energy efficiency finally integrated across all the trades.
- Ensure contractors for post-disaster rebuilding and resilience retrofits are aware of and take advantage of utility energy efficiency programs and rebates.
- Develop resilience/efficiency curriculum for professional degree programs for consistent competency

Structure (2)

- Comprehensive fire retardant, uplift resistant, efficient roof/attic system – Above deck insulation, ventilation, radiant barrier
- Structural/thermal safe room
- Smart utilization of thermal mass for energy efficiency and resilience – foolproof in case of power outage.
- Begin conducting experiments to quantify drying potential of wall assemblies that have been exposed to floods

Windows and Shading (1)

- Highly insulating windows for survivability in cold climate
- Automated roller shades/shutters
- Dynamic windows to reduce heat gain

Other Technologies (0)

- R&D on fire suppression as VRF (variable refrigerant flow) system
- Transactive energy based on blockchain with sovereign identity built in (privacy)

Group 2: Operations

Valuation/Metrics

- [9] Community standards/benchmark for EE and resilience; research analysis on EE or LF valuation for resilience **(6)**
- [11] Insurers need to incentivize resilience measures make resilience conditions of TIF project **(6)**
- [16] Integration with decision systems. Natl $ per resilience measure SAIPI impacts (scout-BTO, intelligence dashboards-utilities, war gaming-military) **(5)**
- [17] Coordinating zoning and building codes with resilience and EE. **(5)**
- [1] Research analysis on EE/LF valuation for resilience
- [10] Metrics (target) benchmark, characterization. Resilience factor (compact of EE, Energy)
- [12] Overlap/stack use cases for grid uses and disaster recovery & quantify values. Help prevent outages but maintain quality of life during disaster.
- [13] Resilience indicator for MLS including EE
- [16] Model & methodology development for valuing resilience and co-optimizing resilience and EE.

Knowledge and Awareness

- [4] Incorporate to "advance energy/resilience design guide" **(7)**
- [6] Update workforce & education programs for resilience needs of vulnerable communities **(7)**
- [1] Create public demand by making it cool (sexy); make it fun (gamification); creating value (appraisals); impactful (GHG reductions)
- [2] Integration of EE/resilience into education curriculum on all levels
- [3] UL listing of HIT for resilience/EE
- [5] Hydrogen town?
- [7] Identify cost barriers in deployment of retrofit automation technology: Address with technology and policy

Financing

- [20] Costs and financing: Work with long-term institutional investors; market vehicles for long dated assets **(7)**
- [20] Expansion of commercial PACE financing for resilience

Collaboration

- [8] Align with utility goals **(6)**
- [18] Leverage resilience investments to improve equity and increase community engagement.
- [18] Working group/initiative on resilience to break silos & add value streams
- [18] RIO to insurance co./FEMA (data)
- [18] FHA for integrated resilience and EE investments i.e., green bonds deployed in LIC 1st
- [19] Public/private partnerships to address engineering challenges with existing technology solutions
- [19] Connect municipal and/or non-profit and/or commercial facilities with residents for resilience
- [14] Legal Authority/Franchise/Row: mini-muni; energy improvement district; Common law → explicit statute.

Smart systems AI and Data

- [28] Programmable matter (changes properties under resilience event)
- [29] Dedicated infrastructure w/ centralized comms & controls (e.g., Emergency Broadcast System to people and building automation

systems or smart home equipment; dedicated computing and process -NOAA hurricane landfall)

- [34] Blockchain-informed mesh grid. Blockbuster vs YouTube/Bus vs Uber
- [36] Platform technology in building to automatic operation of equipment using AI driven approaches: Jarvis for buildings
- [39] Centralized data repository for resilience of EE technologies. Jurisdictions looking for support: new app and pilot program.
- [31] Harness data to learn about state of health of system through AI/ML → give to O&M

Miscellaneous R&D

- [30] Self powered furnace: black start equipment
- [35] Biosphere: District of building-level independent, self-sustaining, livable spaces (NASA habitats, military bunkers)
- [37] Passive house for efficiency & resilience: Superior, filtered IAQ; reduced energy required for 100% renewable "self-power"
- [27] "Thermal" grid interactive building
- [32] R&D of cost-effective solutions that can complement both EE and resilience, * particularly portable devices that can be DIY in existing buildings in reduced mode.
- [23] Market ready renewable hydrogen fuel cell
- [25] Building science research for nexus of resilience & EE across different situations

HVAC

- [15] Next generation HVAC/RTU design with new requirements: Modularity, Controllability, Resilience. Efficiency and grid integration and resilience. For example, a 4-ton unit is using 4x 1-ton compressors for modularity in control (grid) operation (during an event) and efficiency (passive-load vs TOU load). Novel controls and power electronics to integrate renewables and storage. **(10)**
- [15] Advanced multizone buildings/Air distribution systems/variable capacity HVAC/Air filtration

Sensors and Controls

- [39] Low-cost self-powered peel-and-stick wireless sensors: data to decisions
- [26] Development of advanced and resilient controls to improve efficiency and resilience.

Structure and Modular Buildings

- [21] Modular construction that incorporate & prefabrication resilience and energy efficiency.
- [38] Tech for manufactured housing needs "PV on a pole"
- [33] Research → More resilient building structures: Materials; construction methods; testing; etc.
- [24] Transformational R&D for buildings environmental technology with retrofits and resilience considerations in mind

CHP

- [22] Building-integrated CHP and storage as well as community-scale CHP and storage: "Efficiency and resilience"

APPENDIX D. ACTION PLANNING TEMPLATE

Opportunity Title:		
Description: Write 2-3 sentences or bullets to summarize the opportunity. Explain the dependencies – how might the opportunity differ by climate zone, hazard exposure area, connectivity to grid, commercial vs residential, or other factors?	**Key Challenges Addressed:** What are the key challenges that will be addressed if this opportunity is successful?	**Desired Outcome:** Describe the desired outcome achieved through this opportunity and the benefits to different stakeholders (e.g., occupants, owners, utilities, communities, financial interests).

Key Milestones: What are the 3-4 milestones along the path to achieving the desired outcome?	**Task Plan:** What R&D or other **activities** are needed to address challenges, reach milestones, and achieve the desired outcome? Describe a possible approach to addressing this opportunity, including 4-8 essential steps.	
Milestones	Activities (aligned to milestones, as applicable)	Approx. Time Frame

Key Collaborators: Who should lead and who should contribute to this effort and how?

Stakeholder	**Role**
DOE/BTO	
National Labs	
Other Fed. Gov.	
State/Local Gov.	
Communities	
Utilities/PUCs	
Emergency Managers	
Builders & Manufacturers	
Owners	
Occupants	
Academia	
Other	