Building Efficiency for Energy Resilience: Analysis and Applications for States and Local Governments

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ABSTRACT

Since 1980, the U.S. has experienced 376 weather and climate disaster events that exceed $1 billion in damages, with homes and buildings and the people inside them, experiencing some of the worst effects. Recent research from DOE shows how building energy codes, through enhanced building envelope, can help mitigate some of the damage by improving passive survivability to allow occupants to stay safely inside a building for a longer period during an extreme temperature event. The 2022 Summer Study paper “Trials and Tribulations of Valuing Building Energy Resilience” introduced a methodology to quantify the resilience benefits of energy codes, including the use of metrics like extreme temperature event hazard risk, Standard Effective Temperature (SET), property damage, and excess mortality. This follow-up paper applies the developed methodology to explore how states and local governments can leverage the research to consider the resilience benefits of energy efficiency to prepare for and reduce the severity of climate change impacts on the built environment. The paper explains procedures for assessing the impact of an enhanced building envelope on passive survivability to aid in resilience planning and policy development. Examples of applied methods include assessing hazard risk, discerning synergies and conflicts between energy efficiency and thermal resilience, and quantifying the efficiency and resilience benefits of current and stretch energy codes. Additional considerations describe the challenges faced by disadvantaged communities, a population group that can be disproportionately harmed during extreme temperatures, and tools that support identifying needs and prioritizing efforts.

Background

Weather and climate disasters are increasing in frequency and intensity, and as a result, we’ve endured a record number of large disaster events in recent years. Since 1980, the U.S. has experienced 376 weather and climate disasters, each resulting in monetary damages of $1 billion or more. The cumulative cost for these events exceeds $2.4 trillion. In 2023, the U.S. experienced 28 weather and climate disasters that each exceeded 1 billion dollars in damage costs. That number puts 2023 as the year with the highest number of billion dollar disasters, with combined total damages of nearly $93 billion. This is closely followed by 2020 as the second-highest number of billion dollar disasters with 22 events and then 2021 in third with 20 events (NCEI 2024).

States and communities, and especially communities with socially vulnerable populations, endure the worst of the costs and impacts from these disasters. In response, many communities have developed or are in the process of developing resilience plans. A 2023 study from ICF for the Pacific Northwest National Laboratory identified steps a local government could take when developing plans to help bolster community resilience, which include such activities as creating resilience hubs, collaborating with energy and water utilities, and implementing updated building codes (ICF 2023).

Resilience is defined as the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events (NRC 2012). The resilience of a building is dependent on its ability to provide continuous services to building occupants in the face of a threat, and therefore the utility grid; the availability of energy fundamentally shapes how a building operates during an adverse event. Acknowledging this relationship, this paper focuses on the energy resilience of buildings and the ability for occupants to shelter in place in the event of a power outage during temperature extremes. It applies these findings to potential applications for states and local governments to inform their investment and policy decision-making, including efforts to improve resilience through the adoption and implementation of strong building codes.

Methodology

Based on identified research gaps, U.S. Department of Energy (DOE) Building Technology Office (BTO) funded a multi-year research project, conducted as a collaborative effort between three DOE research laboratories to develop a quantitative methodology for valuing building energy resilience against extreme temperature events.[1] This section offers an overview of the developed methods and key findings, which form the basis for its suggested applications for states and communities illustrated later in the paper. A more detailed discussion of the methodology can be found in the study's technical publications (Franconi et al. 2024, Franconi et al. 2023).

Scope and Approach

The scope of the research project includes developing and applying a methodology to quantify the resilience benefits of building energy efficiency, particularly as it relates to energy code adoption. The assessment focuses on extreme heat and cold events that result in a power outage. It is conducted for representative U.S. geographic regions, climate zone locations, building types, building conditions, and improved efficiency cases. Figure 1 presents the project analysis scope. This includes new and existing single-family (SF) homes and multifamily (MF) apartment buildings, each evaluated at three levels of efficiency and simulated in six climate zone locations.

The efficiency improvements are tied to requirements specified in current model energy code (MEC)[2] and stretch code. The current MEC for residential buildings is the 2021 IECC (ICC 2021). The current MEC for commercial buildings is ASHRAE Standard 90.1-2022. The stretch code package is informed by envelope and infiltration requirements included in the 2021 Passive House Institute U.S. (PHIUS) Standard (PHIUS 2021). For existing buildings, the base case condition is characterized by published county-level housing survey and utility data. For new buildings, the base case condition is represented by historic model energy code, which is the

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[1] The original project research team includes: PNNL overall project manager Ellen Franconi and PNNL staff Luke Troup, Mark Weiner, Yunyang Ye, Chitra Nambiar, and Jeremy Lerond; NREL project manager Eliza Hotchkiss and staff Jordan Cox, Sean Ericson, Eric Wilson, Philip White, Conor Dennehy, Jordon Burns, Jeff Maguire, and Robin Burton; LBNL project manager Tianzhen Hong and staff Linqian Sheng, and Kaiyu Sun.

[2] MEC are available for adoption by states and local jurisdictions. The 2021 IECC is recognized by U.S. DOE as the current MEC for residential buildings. ASHRAE Standard 90.1-2022 is recognized as the current MEC for commercial buildings.

2006 IECC for SF buildings and the ASHRAE Standard 90.1-2004 for MF buildings. Impact of the efficiency-resilience mitigation is assessed by comparing the building energy performance, occupant exposure, and property exposure determined for the base case condition with that determined for the improved conditions.

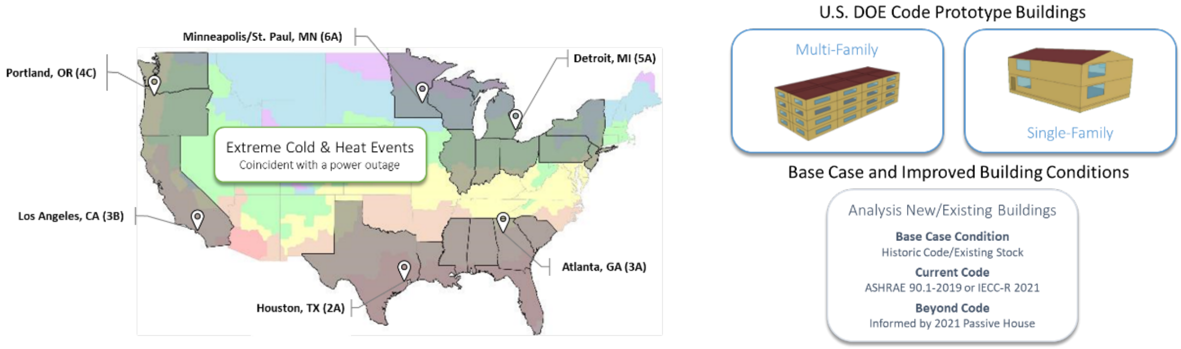

Figure 1. Project analysis scope

Workflow and Methods

The impact of improved efficiency on building energy performance can be assessed using building models and simulation analysis. To consider the resilience aspects of improved efficiency, traditional building simulation performance assessments can be expanded to include additional considerations, such as hazard risk, potential damage to occupants and property, and the monetization of resilience-related impacts in the economic analysis. The developed methodology includes this expanded scope. A description of the four assessment components is presented below.

(1) Hazard risk identification quantifies the hazard probability and thresholds. It includes identifying representative extreme heat and cold events using historical and future projected weather data. From the collection of identified events, representative heat and cold events are selected to be used in the performance analysis. Establishing the risk probability involves evaluating the frequency of power outages occurring during extreme heat or cold for each location studied. The risk probability is applied in the cost effectiveness analysis to annualize the losses determined for each representative event.

Extreme heat and cold events were identified following methods described by Ouzeau et al. (2016) from historical weather data published by NASA (Stackhouse 2021) for years 2010 through 2020. To evaluate the coincident probability, the dates of the identified extreme events were cross referenced against power outage data reported on form OE-417 by U.S. utilities to the DOE Office of Cybersecurity (DOE 2018). To usefully apply the outage data, several assumptions were made, including that a reported outage affected the entire state. This affects the accuracy of the probability estimate, which may result in the value be overstated for larger states.

(2) Exposure analysis uses building performance simulation analysis to evaluate the impact of improved building efficiency on energy use during typical weather conditions. It also includes using performance simulation to assess indoor conditions during extreme heat and cold events coinciding with a power outage. Occupant exposure is assessed by calculating passive survivability metrics using simulation output data. More details about these metrics are provided in the next section of the paper.

For the study, existing single-family buildings (SF) are modeled using ResStock. ResStock couples statistically representative residential household and efficiency characterizations with the OpenStudio building modeling interface (Langevin 2019). Approximately 3000 single-family buildings were selected from the population of buildings in the area to represent the existing buildings in each of the six locations analyzed. The new SF and new and existing multifamily (MF) building performance are modeled using the EnergyPlus™ building simulation engine. The new building simulation models are developed from the DOE code prototype building models.

(3) Vulnerability assessment translates the effect of exposure to extreme heat and cold by the occupants and assets (e.g., property) to damages incurred. Damage in regard to human health is dependent on several factors, including age, gender, socioeconomic status, and climate adaptation. For the study, damage to occupants due to exposure is considered in terms of excess mortality. Additional health impacts, which do not result in death, can be caused by exposure associated with extreme temperature events, including hospitalization, emergency room visits, and self-treated illness. However, adequate information in published literature was not sufficient to support quantifying these damages and they were not accounted for in the analysis.

In this study, the impact of occupant exposure to extreme heat and cold was evaluated using fragility curves published by Gasparrini et al. (2015). Using recorded extreme temperature events and death records, Gasparrini et al. assessed mortality rates across temporal variations to determine the relative rate as a function of daily average outdoor temperature. The fragility curves are published for 384 global locations, including 132 U.S. cities. The curves are applied in the study to estimate the impact of increased efficiency on mortality rate during seven days of an extreme temperature-power outage event. For the assessment, we used daily average indoor temperature data determined from the building simulation analysis for the base and code cases. Applying indoor temperature data to the fragility curves may introduce a bias in determining the mortality rate (e.g., underestimate the value). But it is a plausible approach for assessing the change in mortality rate attributed to improvements in efficiency. For example, any bias introduced to the mortality estimates determined for the base and code cases would be reduced due to a cancellation of the error.

For property exposure, data published in the FEMA National Risk Index Database (FEMA 2020a) were examined to estimate the impact of damages incurred. The database provides data for U.S. states at the county level. But the building loss records appear to be incomplete and underreport damages associated with heat and cold waves. Insurance records may provide a better indication of damages. However, their collection and assessment were beyond the scope of the study.

(4) Mitigation valuation includes monetizing benefits and damages and considering annualized impact (Weimar et al. 2018). In the assessment, excess mortality is the resilience impact that is monetized. Its monetization is based on the value of a statistical life, estimated at $10 million per life based on 2020 dollars. The value is in the range of published estimates (FEMA 2020b, Viscusi 2020).

The overall mitigation valuation includes traditional economic costs and benefits typically considered when analyzing the cost effectiveness of energy efficiency investments. These include annual energy costs, the societal value of greenhouse gas emissions, and the efficiency measure costs. Energy costs are based on U.S. averages published by the Energy Information Agency (EIA 2020a and 2020b). The societal cost of greenhouse gas emissions is derived from data prepared for the U.S. government and published by the Interagency Working

Group on the Social Cost of Greenhouse Gases.[3] First costs determination follows procedures applied to evaluate the impact of newly released model energy code requirements, as documented by Hart and Liu. (2015). The efficiency measure first costs are based on U.S. average estimates with multipliers applied to account for regional differences. For new buildings, the costs represent the incremental increase in implementation costs relative to base case construction costs. For existing buildings, the first costs are not assumed to be incremental.

Metrics

The valuation methodology includes the calculation of thermal resilience metrics, occupant damage metrics, and economic metrics. Table 1 lists the key metrics used in the study. The metrics can be compared individually or in combination with other metrics to assess the relative impact of efficiency-resilience strategies to support mitigation planning and investment prioritization.

Table 1. Key Metrics Used in the Study

Category	Name	Description
Thermal resilience metrics	Standard Effective Temperature	Indoor comfort condition metric that considers dry-bulb temperature, relative humidity, and other factors.
	SET Degree Hours	Cumulative hourly SET degrees that fall outside of a specified range (e.g., 54°F to 86° F).
	Days of Safety	The time elapsed during which the SET degree hours do not exceed a threshold of 216.
Occupant damage metrics	Excess deaths	Deaths attributed to occupant exposure due to an extreme temperature event.
Economic metrics	Investment cost	First costs for the measure package.
	Cost savings	Evaluated based on a typical weather year.
	Emission savings	Societal value of reduced greenhouse gas emissions.
	Excess mortality	Losses associated with excess deaths based on $10 million per lost life.
	Annual coincident probability	Location-specific annual coincident probabilities of a power outage occurring during extreme heat or cold.
	Benefit cost ratio (BCR)	Annualized energy cost savings, emissions savings, and extreme event monetization.

The building simulation analysis provides performance results that can be used to calculate metrics that indicate occupant exposure. Occupant exposure is quantified and expressed as thermal resilience metrics, which may also be referred to as passive survivability metrics. For example, standard effective temperature (SET) is a thermal comfort metric that combines the effect of indoor dry-bulb temperature, relative humidity, mean surface radiant temperature, and air velocity, while also considering the anticipated activity rate and clothing level of occupants.

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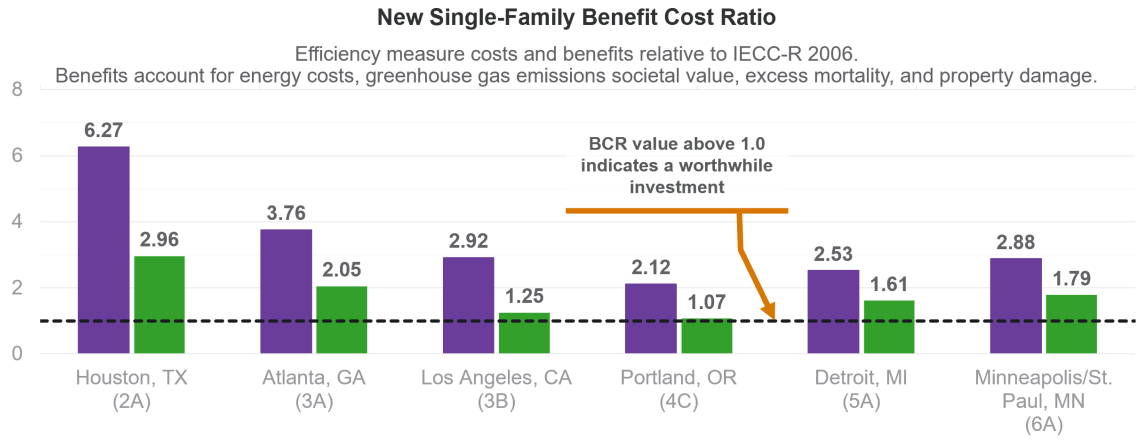
[3] The Technical Support Document presents interim estimates of the social cost of carbon, methane, and nitrous oxide developed under Executive Order 13990. Accessed on June 14, 2022 at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

SET degree hours is a cumulative measurement of SET degrees that fall outside a specified temperature threshold. Days of Safety indicate the elapsed time in which habitable conditions are maintained. The threshold values, indicated in Table 1, for the SET degree hours and Days of Safety metrics are consistent with those defined for the USGBC LEED Passive Survivability Pilot Credit. These two valuation metrics that indicate the ability to shelter in place, SET degree hours and Days of Safety, are included in the output reports of the EnergyPlus™ building simulation program and can be readily applied to compare the resilience benefit of increased efficiency.

Traditional economic metrics included in the analysis are mitigation measure capital cost, energy cost savings, and energy emissions reduction. In the study, reductions in excess deaths are determined for representative heat and cold events for each of the six analysis locations. To consider these effects as part of traditional net present value benefits and costs, event impacts need to be annualized by multiplying by the annual coincident risk probability, which is location and event type (heat or cold) specific.

Economic Results

A net present value economic analysis was completed to demonstrate how monetized benefits from improved resilience can be incorporated into efficiency cost effectiveness calculations. The data that characterize the impact of efficiency on building performance improvements and occupant damage reduction are provided in Figure 2. The figure shows the benefit-cost-ratio (BCR) values for two building types: (1) new SF buildings and (2) the median existing SF building (based on the representative population of existing buildings modeled). The BCR is the ratio of the annualized net-present-value of the efficiency-resilience benefit and the efficiency investment first cost. It indicates the dollars of benefit received from every dollar of investment. A BCR value greater than one typically indicates a worthwhile investment. The efficiency-resilience benefit of new code adoption ranges from 2 to 6 for new buildings and from 0.3 to 0.8 for existing buildings. For stretch code, the values from 1 to 3 for new buildings and from 0.3 to 0.7 for existing buildings.



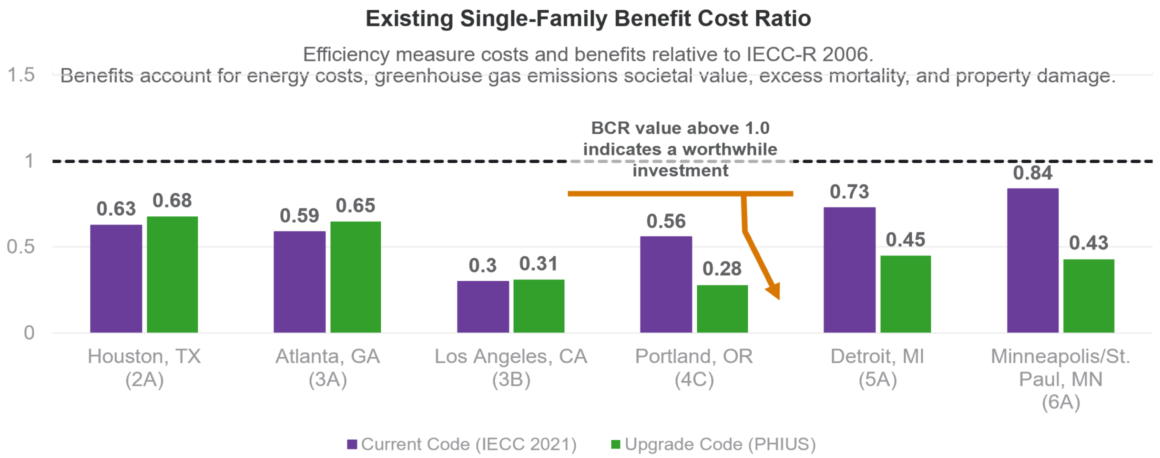


Figure 2. Benefit-Cost-Ratio Values determined for Current and Stretch Code Adoption for New and Existing Single-Family Buildings

The quantification methodology and BCR assessment demonstrates the general approach for incorporating resilience benefits into typical increased building efficiency economic evaluation. The reported values are considered preliminary for several reasons though. Efficiency-resilience benefits associated with improved health (other than reduced mortality) and reduced property damages are not considered. The data used to estimate coincident risk probability lack resolution. To compensate, assumptions were made in its determination, which tend to overstate the risk for larger states. In addition, the coincident risk assessment is based on 10 years of historical data, which may not reflect future risk. Building performance and occupant comfort are also based on historical weather data, specifically the extreme temperatures extracted from representative events occurring between 2010 and 2020. In summary, the effect of global warming on the intensity of extreme heat and cold events occurring over the 30-year investment lifetime is not considered, nor is their impact on grid reliability and coincident risk probability.

Anticipating Future Hazard Risk and Damage Potential

In follow-on work to the original research, PNNL is evaluating the impact of global warming on extreme temperature events. For the assessment, future weather is based on projections developed for 2045 through 2054 for the representative concentration pathway 8.5 (RCP8.5), which follows the current global warming trends through 2100 (IPCC 2014).[4] In Figure 3, the range of anticipated hourly temperatures (left charts) and extreme heat events identified from daily average temperatures (right charts) are shown for Houston (a) and Minneapolis (b). The hourly temperature quartile charts compare annual typical meteorological year temperature data (derived from 1991-2005 datasets) with the temperatures recorded from 2014-2023, and temperatures based on the RCP8.5 scenario projected for 2045-2054. For the two example cities, Houston and Minneapolis, the RCP8.5 data indicate 9% (6.2 F) and 15.6% (7.2 F) increase in median temperature, respectively, relative to the TMY data.

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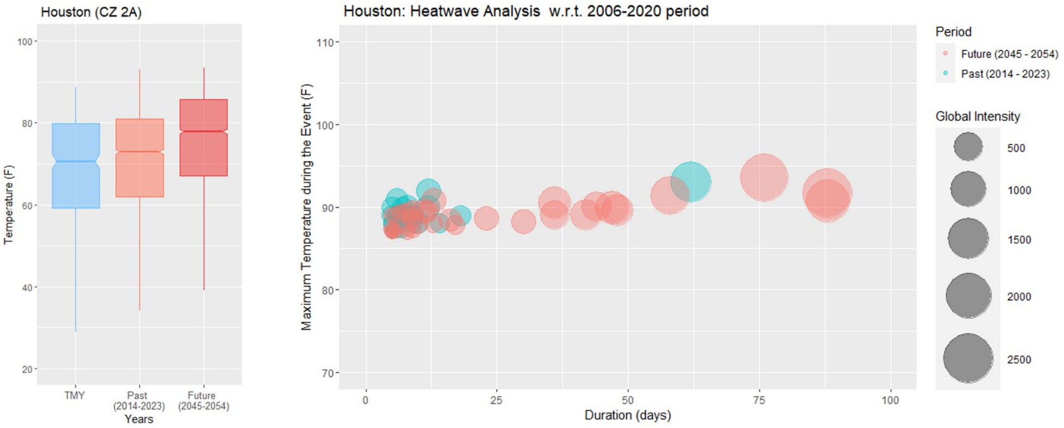
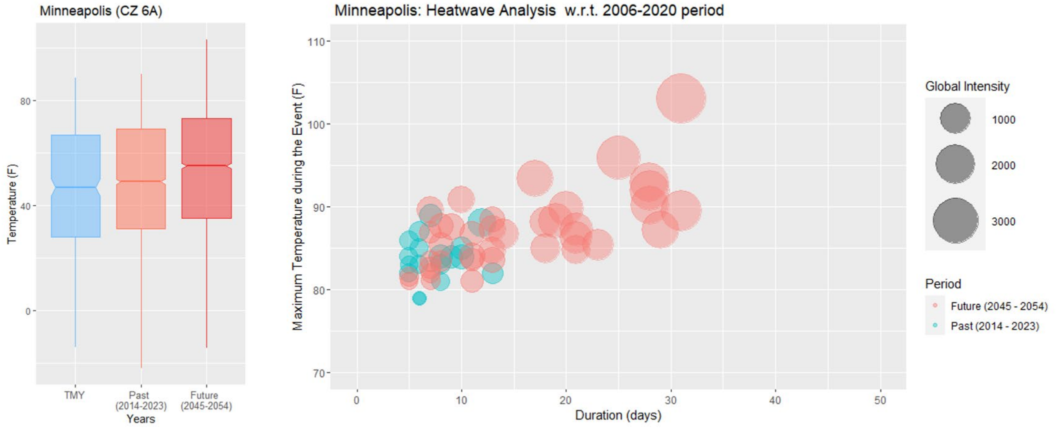
[4] The IPCC reports that scenarios without additional efforts to constrain emissions lead to pathways ranging between RCP6.0 and RCP8.5. Scenario assumptions include factors affecting the size of anthropogenic emissions and the carbon warming feedback loops in natural systems. Yet due to the uncertainties associated with the latter, any particular level of anthropogenic emissions could lead to higher or lower scenario atmospheric concentrations depending upon the strength of the eventual feedback loop.



(a) Houston



(b) Minneapolis

Figure 3. Historical and Future Temperature Data for (a) Houston and (b) Minneapolis

The occurrence of extreme events, indicated in Figure 3, were identified following the method of Ouzeau et al. (2016). The charts show the duration, frequency, and overall intensity of events identified from recent historical data (2014-2023) and future RCP8.5 projections (2045-2054). The thresholds for identifying the events are based on the same reference period for both data sets, which are average daily temperature distributions occurring between 2006-2020. The graphical presentation and the use of a consistent reference period support making comparisons between the characteristics of recent to future extreme temperature events in terms of frequency, maximum daily temperature, duration, and overall intensity. For example, in Houston, the average maximum intensity for the heat events does not vary between recent and future projected events but their duration extends from an average of 10 days to 24 days. For Minnesota, the average daily temperature during heat events increases from 84 F to 87 F and the duration from 8 days to 15 days.

Figure 4 shows the histograms of average daily temperatures for the recent historical data and the RCP8.5 future scenario. It also includes the Gasparrini fragility curves published for

Houston and Minneapolis. The curves serve as a relative indictor of the potential impact that current and future temperatures can have on occupant exposure and health impacts. The dashed lines indicate the 2.5% and 97.5% temperature distributions for the data sets. The dotted line indicates the minimum mortality temperature aligned associated with the fragility curve. The charts show that the distribution thresholds shift right for future weather years, indicating the increased frequency of occurrence of hotter temperatures. The slope of the fragility curve during the hottest days indicates the rate of increase in excess mortality associated with the increased frequency.

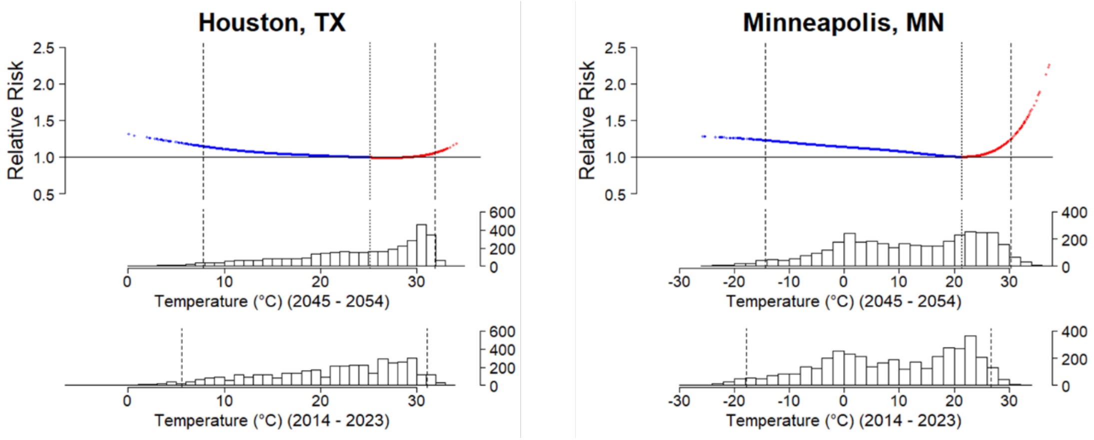


Figure 4. Population Vulnerability to Heat and Cold in Minneapolis

States and other entities can consider conducting assessments using future temperature projections, such as those shown in Figure 3, to evaluate the potential for extreme temperatures in the next decades to understand how efficiency-related policy decision made today can help ensure building thermal resilience in the future.

Resilience Assessment for States and Communities

Building codes establish minimum requirements for the design, construction, and performance of building systems, which include numerous provisions supporting resilience. These include structural specifications for wind and snow loads, to fire and moisture resistance. Building energy codes, a subset of building codes, establish minimum requirements for building energy performance, making energy efficiency an inherent and fundamental component of resilience. Energy codes provide a direct benefit to the energy resilience of buildings, from increased thermal resistance and ability of the building to maintain comfortable indoor environments, to limiting unwanted air infiltration (which is a primary source of moisture and durability issues) while maintaining healthy levels of ventilation and indoor air quality. Energy codes also contain accepted methods for specifying and sizing building systems, such as HVAC and lighting, which ultimately determine a building’s operational power needs and peak demand, thereby enhancing the resilience of the broader utility grid.

For the evaluation of resilience benefits of energy codes to make the largest impact for state and community stakeholders, the ultimate application for the developed methodology is the evaluation of monetized benefits of improved resilience. While the methods provide a foundation for establishing such standardized procedures, presently the authors recommend exercising caution when relying on the absolute cost effectiveness values for understanding the benefit of efficiency for increased resilience. This is primarily due to limitations in data sources describing risk and damages, which include difficulties linking published utility outage data to location-specific extreme temperature events, extending the application of excess mortality fragility curves to the built environment, characterizing non-mortality health impacts, and evaluating property or other asset damages. While not all analysis components are perceived to be robust, the calculated thermal resilience, occupant exposure, and economic metrics are informative. When compared as relative values (and not on an absolute scale), they indicate different aspects of the impact of the efficiency investment on its benefit to the community, the building owner, and occupants.

By applying the data in this manner, the methods can be used to explore how states and local governments can consider building energy efficiency and its resilience benefits in their decision-making processes to prepare for and reduce the severity of climate change effects on buildings and occupants. Several potential applications for the methods that support such assessments are presented below. The applications target hazard risk assessment, discerning synergies and conflicts between energy efficiency and thermal resilience and quantifying the efficiency and resilience benefits of current and stretch energy code adoption. A discussion is also provided on special considerations for disadvantaged communities since the impacts of extreme weather events can disproportionately harm vulnerable populations.

Demonstrating the Value of Energy Code Adoption

As a policy instrument for state and local governments, building energy codes present a unique opportunity to support improved building performance and energy resilience. Model energy codes are readily adopted and implemented by federal, state and municipal governments. Their provisions are typically coordinated with related industry standards, meet established criteria such as technological feasibility and cost effectiveness, and can provide a direct benefit to key related sectors, such as insurance. Building codes also are frequently lacking in disaster prone areas – either because they use outdated codes or have no code requirements at all – meaning these areas would especially benefit from understanding the resilience benefits of energy codes.[5] However, in a typical state or local energy code adoption process, the data and analysis used to help evaluate and consider adopting a new code is limited to a traditional benefit-cost analysis.[6] While anecdotal evidence of the resilience benefits of energy codes may be discussed in the code adoption process, historically, there has been insufficient data to quantify these benefits. Data and findings in this paper can serve as a starting point for those states and jurisdictions that wish to incorporate resilience benefits into their energy code adoption processes.

For example, thermal resilience metrics can be used to assess the relative impact of efficiency on occupant comfort and the ability to shelter in place. In the study, the metrics are calculated for seven days of the representative heat and cold events for the building during a power outage. Specifically, SET degree hours and days of safety are calculated independently for heat and cold events. The sets of heat and cold metric values can reveal what measures or

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[5] The DOE Building Energy Codes Program tracks and analyzes data related to the adoption, compliance, and implementation with the latest model energy codes. Maps and graphics provide additional context for energy code adoption across the country and are available at https://www.energycodes.gov/infographics.

[6] In areas with greenhouse gas emission reduction goals, emissions reductions may also be considered.

packages of measures may provide desirable or inverse effect across the two event types. For example, particular technologies, such as low solar heat gain windows may be desirable in heat but not cold conditions. Table 2 provides these metric values representative of existing SF buildings in Houston and Minnesota. The values indicate the improvements achieved with current and stretch codes, which result in increased thermal resilience during both heat and cold events.

Table 2. SET Degree Hours and Days of Safety

Location (climate zone)	Extreme Event	Existing single-family median building performance over a 7 day extreme temperature-power outage event					
		SET Degree-Hours (heat event hours > 86 °F, cold event hours < 54 °F)			Days of Habitability (based on 216 SET degree hour threshold)		
		Existing Stock	IECC 2021	Beyond Code	Existing Stock	IECC 2021	Beyond Code
Houston, TX (2A)	Cold	755	168	11	3.5	7.0	7.0
	Heat	600	19	0	4.0	7.0	7.0
Minneapolis/ St. Paul, MN (6A)	Cold	5,374	3,709	2,193	0.6	1.2	2.2
	Heat	236	41	0	6.8	7.0	7.0

Building performance simulation analysis needs to be performed to evaluate these thermal resilience metrics. Thresholds that establish the upper and lower limits to the SET range and the duration for calculating cumulative SET degree hours must also be specified. In addition, to determine days of safety a cumulative SET degree hour target needs to be set. The values calculated in this study are based on thresholds established for the USGBC LEED pilot credit for resilience. The thresholds can be adjusted though to better characterize the vulnerability of a particular population demographic or community. Moving forward, getting expert guidance and industry acceptance for more granularized population comfort thresholds and safety targets would be beneficial.

In addition, Figure 5 demonstrates the benefit of energy code adoption based on metrics indicating normalized annual building energy use (NEUI) and thermal resilience (SET degree hours). The dotted black line in Figure 5 shows the reductions in energy use attributed to residential model energy code adoption (IECC-2006 through IECC-2021). The solid-colored lines indicate changes in SET degree hours for a SF building complying with a code (or using an above-code program) during a 7-day extreme heat event coinciding with power outage for the six climate zone locations. The data lines show that the SET degree hour resilience metric track the general trend of the energy use reductions achieved with code-cycle improvements. The data also reveal the notable impact on thermal resilience that strong passive efficiency requirements can have, as indicated by the PHIUS stretch code package.

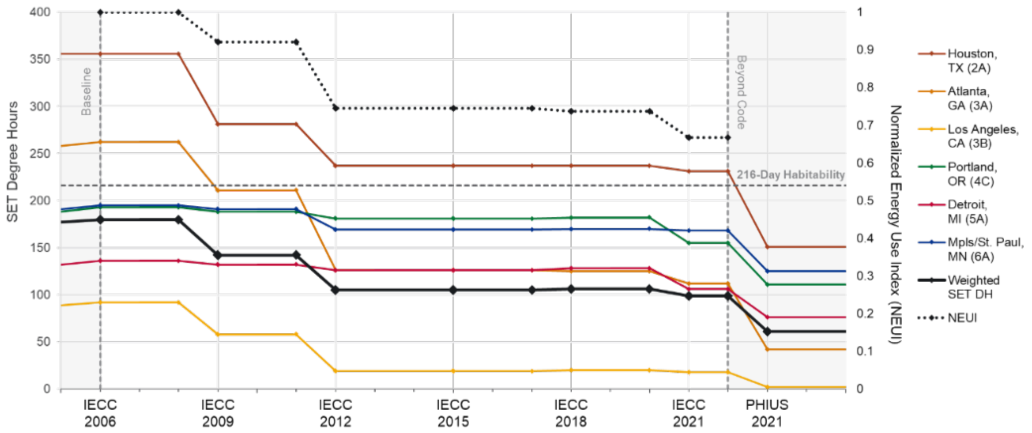

Figure 5. Energy use reduction and thermal resilience improvements

Additional Considerations for Disadvantaged Communities

Historically marginalized and disadvantaged communities, including low-income, communities of color, elderly and disabled, are disproportionately impacted by extreme weather-related events. Studies show that these communities often reside in energy-inefficient homes and have the most exposure and sensitivity to extended power outages and safety risks (Brown et al. 2020). The federal government's focus on energy and environmental justice, catalyzed by the establishment of the Justice40 Initiative[7], centers the needs of historically underserved at the forefront of federal investments. The effort aims to direct the flow of federal resources to overburdened and underinvested communities where the intersections of inefficient housing, climate risk, and energy insecurity are most evident. The application of building efficiency measures cannot just improve the quality and affordability of housing, but address more persistent disparities that support the economic, social, and physical infrastructure of communities.

Traditional energy code programming, however, is unlikely to deliver the same value benefits for lower-income jurisdictions that lack proper resources and capacity to support advanced energy code implementation. A review of 20 energy code field studies found, for instance, that lower income counties saw lower compliance rates than higher income jurisdictions (Nambiar et al 2022). In urban environments, numerous studies have shown that lower-income, non-white neighborhoods experience disproportionate heat exposure due to urban heat island effects (Hsu et al 2021). Targeted programming, funding, and technical support must rectify these structural inequalities to ensure that energy vulnerable communities benefit from energy resilience.

A growing number of geospatial mapping tools are available to help state and local practitioners identify areas in greatest need of investment. In this regard, the Justice 40 Climate and Economic Justice Screening Tool (CEJST)[8] and the Department of Energy (DOE) Low-Income Energy Affordability Data (LEAD) tool[9] support efforts to track and bring awareness to disparities in health, air quality and energy expenditures based on income, housing type, and ethnicity across the nation. Some local campaigns, such as Heat Watch Chicago, have gone one

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[7] Justice40 Initiative | Environmental Justice | The White House

step further to create their own mapping tools that includes local temperature data, community resources, and other inputs that reflect the distribution and impact of extreme heat (CAPA 2023).

State and local partners are also reshaping strategies for equitable engagement and capacity-building to ensure historically underrepresented communities are aware of energy code resources and are part of the decision-making process. For instance, the Resilience Southwest Building Code Collaborative, a project funded through the Bipartisan Infrastructure Law (BIL), is working with local communities across Arizona and New Mexico to build local knowledge and empowerment around the intersection of building codes and unique Southwest considerations like extreme heat and water scarcity (Dokes 2024).

With input from the local community, mitigation programs can be developed to address lack of access to energy-efficient housing and under investment in clean and resilient energy system. Efforts can be prioritized to address these risk-prone populations to meet equity and environmental justice goals, including those defined as part of DOE's Justice 40 that address energy and housing justice.

Application for Resilience Planning and Policy Development

The methodology developed as part of the research study demonstrates a process for calculating a net present value metric, such as a BCR, to more fully value efficiency benefits. However, instead of using a single economic metric, considering a collection of efficiency-resilience metrics can more broadly characterize considerations in terms of extreme event risk, thermal resilience, occupant exposure, health impacts, property damages, and economic impact. Mitigation planning efforts can assess the level of risk and vulnerability across county, census region, or populations in order to prioritize efforts. For each targeted area, the benefits and costs associated with mitigation actions designed to protect the population health and wellbeing can be compared. Customizable methods, such as a decision matrix, that consider stakeholder concerns, data confidence, and initiative objectives may be well-suited for state and local government applications. The approach applies weighting factors to normalized values of selected resilience metrics. Scores are developed for each investment option. The option with the highest score reflects the mitigation solution that best meets the stakeholders needs.

An example of a decision matrix applied to Houston resilience metrics for existing SF building is provided in Table 3. Seven metrics are considered. For each, the data for the two cases are normalized relative to the better value, which are underlined in the table. Weighting factors totaling 100% are assigned to metrics. The total scores for the two cases indicate that the beyond code, PHIUS 2021-informed efficiency package, is the preferred investment option given the weights applied.

Table 3. Example Decision Matrix to Support Mitigation Strategy Decision Making

Existing SF Building in Houston extreme heat event	Value*		Assigned Weights	Normalized Values	
	Current Code	Beyond Code		Current Code	Beyond Code
Reduction in SET Degree Hours	581	600	10%	0.97	1.00
Days of habitability	7	7	10%	1.00	1.00
Lives saved per year	62	93	15%	0.67	1.00
Disadvantaged population served (%)	20	20	10%	1.00	1.00

Annual energy savings (kWh/ft2/year)	3.1	4.1	15%	0.76	1.00
Societal cost savings GHG emissions ($/ft2 year)	0.6	0.8	20%	0.75	1.00
Efficiency improvement cost ($/ft2/year)	0.63	0.77	20%	1.00	0.82
Weighted Normalized Total			100%	0.86	0.94

*Values based on median existing SF building performance in Houston. Savings values relative to existing building performance

Conclusions

Historically, states and jurisdictions have relied on energy codes to help their home- and building-owners reduce their energy bills, and more recently as a means to cut their greenhouse gas emissions. Now, there is a compelling case to be made that energy codes help improve safety and resilience for building occupants during extreme temperature events. In the 2023 research report *Enhancing Resilience in Buildings through Energy Efficiency* DOE and several of its national laboratories have made a first attempt to assign metrics and quantify these benefits. Building on that research, DOE and PNNL developed this paper to provide a framework for states and jurisdictions to apply these metrics and considerations in their own resilience planning efforts.

The identified metrics can be informative to states and jurisdictions, who can use them in comparative assessments to inform planning, policy or investment decisions. There are still opportunities to continue to improve the valuation methods, such as developing a reliable way to monetize the resilience benefits. However, the metrics provide useful insights when comparing different energy code scenarios to each other, such as through the use of a decision matrix. Key metrics, such as SET degree hours, can help states and local governments quantify how long their residents can safely shelter in place when an extreme temperature event coincides with a power outage, which in turn, may help provide critical information when considering the adoption of a more recent and efficient version of the energy code.

To help ensure the needs of disadvantaged communities are addressed, additional metrics can be incorporated into the decision-making processes that help identify the level of energy burden and security, such as those provide in tools like CEJST and LEAD. With community input, mitigation programs can be developed to address hazard risk and make an informed energy resilience plan and investments that support community members' health and welfare. Such efforts to lower energy bills and increase efficiency resilience can greatly benefit from state and jurisdictional adoption of current or stretch energy codes.

In addition to considering new metrics and tools, states and jurisdictions may also start considering the time horizon for new energy code adoption. PNNL's initial evaluation shows that the frequency and intensity of extreme heat events will continue to increase over the next 20-30 years (and likely beyond), meaning that investments in resilience will likely provide even greater value moving forward.

Ultimately the choice to incorporate considerations like longer planning time horizons and new resilience metrics into investments and decision making will need to be determined by states and localities. To aid in this, DOE and its national laboratories plan to continue expanding research to quantify the resilience benefits of energy codes and develop methodologies, tools, and frameworks to enable states and jurisdictions to make informed decisions about their adopted energy code.

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