



Beyond the Building: Strengthening Neighborhood Resilience Through Energy Efficiency Programs

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July 2025

Research Report

ACEEE ::

About ACEEE

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Acknowledgments

This report was made possible through the generous support of Avangrid, National Grid, Northwest Energy Efficiency Alliance (NEEA), New York State Research and Development Authority (NYSERDA), and Vermont Energy Investment Corporation (VEIC). The authors gratefully acknowledge external reviewers, internal reviewers, colleagues, and sponsors who supported this report. External expert reviewers included Harold Neale from Avangrid, Eric Olson from NEEA, Cory Blad and Erika Jozwiak from NYSERDA, Laura Capps from VEIC, and Jeff Maguire from the National Renewable Energy Laboratory (NREL). Internal reviewers included Nora Efram, Steve Nadel, Matt Malinowski, and Mike Specian. The authors also gratefully acknowledge the assistance of Russel Like from EPRI, Peter Larsen from Lawrence Berkeley National Laboratory, and Nick Patane and Ke Wei from NYSERDA. External review and support do not imply affiliation or endorsement. Last, we would like to thank the following members of ACEEE's editorial and communications team: Mary Robert Carter, Lynn DeRocco, Kate Doughty, Rob Kerns, Nick Roper, Mark Rodeffer, Ethan Taylor, Roxanna Usher, Keri Lee, and Mariel Wolfson.

Suggested citation

Srivastava, Rohini, Emily Garfunkel, and Lyla Fadali. 2025. *Beyond the Building: Strengthening Neighborhood Resilience Through Energy Efficiency Programs*. Washington, DC: ACEEE. www.aceee.org/research-report/b2505.

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Glossary

Although there are many different definitions for some of these terms, in this report we define them as follows:

Reliability: In the context of utility power distribution, reliability is defined as the ability to maintain electric power delivery, related both to withstanding disruptions and meeting electricity demand (Carvalho, Frick, and Schwartz 2022; Eto et al. 2020; [NERC 2024](#)). The standard measures of reliability are set by IEEE Standard 1366; those commonly used by electric utilities in reliability planning include System Average Interruption Duration Index, System Average Interruption Frequency Index, and Customer Average Interruption Duration Index.

System Average Interruption Duration Index (SAIDI): The number of minutes of interruption experienced by the average customer annually (Sullivan et al. 2018).

System Average Interruption Frequency Index (SAIFI): The number of service interruptions experienced by the average customer annually (Sullivan et al. 2018).

Customer Average Interruption Duration Index (CAIDI): The average restoration time for an outage experienced by the average customer (Sullivan et al. 2018).

Resilience: The electricity sector's ability to adapt to, withstand, and recover from events (FERC 2018; NGA/NASEO 2021). As per the National Standards Practice Manual, resilience is generally defined in relation to severe and long-term events that can cause power outages and is centered on critical services (NESP 2024).

Building energy resilience: Connected to both energy system resilience and community resilience, building energy resilience allows building occupants to maintain operations during extreme events; enhances comfort and safety before, during, and after events; and supports system recovery after an outage (Srivastava, Garfunkel, and Wood 2024).

Passive survivability: The ability to maintain habitable and safe indoor conditions during energy outages or interruptions in fuel deliveries (DOE 2023; Franconi et al. 2023; ULI 2022).

System recovery: A system's capacity to recover rapidly and cost efficiently from a power interruption (NIAC 2009).

Hosting capacity: An indicator for traditional utility distribution planning and grid resilience needs that helps estimate the distributed energy resources that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.

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Executive summary

Key findings

- Building energy efficiency retrofit programs improve resilience to extreme weather events, allowing buildings to maintain safe and comfortable conditions during power outages and reduce the overall stress on the grid. When utilities either do not evaluate the resilience benefits from building upgrades or evaluate only their impacts at the level of a single building or the grid, they undervalue the collective impact at the neighborhood scale—where multiple buildings have energy efficiency solutions.
- Quantifying the resilience benefits from building retrofits in terms of lower peak demand, reduced outage time, and decreased interruption costs can provide a simplified, more strategic approach and enable utilities to prioritize investments to address risks from extreme events.
- Programs should consider targeting multiple buildings in a specific neighborhood for energy upgrades to maximize participation and achieve the resilience benefits at the distribution grid level that are modeled in our study.
- Our analysis of approximately 4,000 commercial buildings and 40,000 households in southeast Westchester County, New York, finds that pairing building envelope measures with heat pumps and implementing them in multiple neighborhood buildings can reduce peak summer demand by 8% and lower the hours of outages in the absence of demand response programs by 63% during the peak summer month.
- Though our analysis is limited to one part of Westchester County, we expect that efficiency upgrades would result in resilience benefits in other areas. To determine the specific resilience benefits of efficiency upgrades in other regions, analysis based on building stock, climate conditions, utility distribution capacities, and retrofit solutions is needed.
- Regulators and policymakers should require utilities to integrate the value of resilience from energy efficiency upgrades into their cost-benefit analyses, help standardize methodologies for valuing the resilience benefits, and encourage reporting of resilience data from programs to improve transparency and inform program planning and future investments.

Today's extreme weather events often result in prolonged power outages, economic losses, and risks to public safety, highlighting the urgent need to improve the resilience of our buildings and grid system. Utility energy efficiency retrofit programs, such as building weatherization and equipment replacement programs, are a cost-effective, low-emissions approach to help buildings maintain safe and comfortable conditions during power outages and reduce overall stress on the grid. This report examines how

utilities evaluating these strategies for program planning and screening decisions can estimate improvements in a neighborhood's collective resilience when multiple buildings have efficiency upgrades.

Valuing resilience at the neighborhood level can inform how investments are prioritized

Utilities and policymakers often struggle to fully quantify the value of building efficiency upgrades for local neighborhoods to understand the aggregated impacts on total savings, costs, and continued reliability and customer safety. Existing methodologies focus on evaluating the benefits of building upgrade investments on the level of either a single building or the utility grid system. This limits the adaptability of the approaches to (1) aggregate resilience benefits from a group of building upgrades at the neighborhood or community level and (2) understand how those upgrades impact overall resilience and grid stability.

Given the deficiencies and complexity of traditional methods, a simplified approach that quantifies key resilience benefits across a group of buildings and the grid can inform a more structured framework for program screening and investment. By focusing on key metrics such as lower peak demand, shorter outage time, and lower interruption costs, utilities and policymakers can simplify the integration of resilience benefits into cost-benefit analyses and better prioritize investments. Furthermore, a simplified approach can help bridge the gap between individual building-level performance and overall grid resilience.

Four steps can help integrate resilience benefits in decision-making

For decision-makers to prioritize retrofit measures that offer resilience benefits, they must understand the risks of weather and climate events (using the latest climate data to model their impact) and identify the geographical location with a mix of residential and commercial buildings that are most vulnerable. They can then analyze energy efficiency retrofits that address resilience gaps, accounting for both current usage and the impact of efficiency measures, and ways to calculate and communicate the resilience benefits from investments. We explain these considerations in detail in this report and recommend steps that utilities and policymakers can take to estimate the value of resilience from energy efficiency investments.

Our analyses of resilience benefits for a study area in Westchester County, New York, finds that coordinating retrofit solutions—such as pairing building envelope measures with heat pumps upgrades and implementing them at the neighborhood scale—avoids exacerbating grid vulnerabilities and helps maintain reliable power. Retrofit measures play a crucial role in enhancing overall building and system resilience by reducing demand during peak periods (up to 8% on a peak summer demand day); shortening outage duration (63% lower in the peak summer month of September); and reducing costs associated with interruptions.

Actions to improve resilience valuation

While improving grid reliability and resilience has received policy attention in recent years—such as through winterization regulations and performance credit mechanisms—demand-side measures such as energy upgrades that improve building resilience and reduce strain on the grid during extreme weather events have not featured as prominently in regulatory decisions. By considering actual climate data and neighborhood energy consumption patterns, utilities and policymakers can make more informed decisions about where to invest in energy efficiency and electrification to improve grid stability and

community resilience during extreme events. The following actions can further advance the integration of resilience impacts into cost-benefit analyses and encourage greater adoption of demand-side solutions.

Actions for regulators

- Accelerate the adoption of resilience valuation methodologies, including guidance for how utilities assess and incorporate the value of resilience into their investment decisions to inform program screening and selection processes.
- Standardize metrics for resilience—such as for reduced peak demand, reduced outage duration, and lower interruption costs—so that utilities can more accurately assess and compare the impact of different energy efficiency measures on building and grid resilience.
- Develop approaches for identifying the beneficiaries of resilience investments, especially in vulnerable communities, and allocate the cost among customer groups.

Actions for utilities and program administrators

- Move beyond the individual building-customer level to a neighborhood-scale perspective on the resilience benefits from building energy efficiency measures to help reduce collective disruptions and ensure more stable energy systems during extreme events; this benefits both individual buildings and the grid.
- Conduct detailed analyses of energy efficiency measures at the neighborhood scale using program participant data to help utilities compare costs and their impact on enhancing the value of resilience for better program design, planning, and evaluation. These analyses can help promote and scale energy retrofits by highlighting their energy and resilience benefits.

Actions for federal and state policymakers

- Advocate for policies and incentives that subsidize energy efficiency upgrades, such as building envelope upgrades, to reduce barriers to adoption for building owners.
- Assess the cost of electrification for customers and provide financial incentives to reduce the higher upfront costs of electrification measures, which have the potential to reduce peak loads, minimize outage durations, and decrease interruption costs, thereby enhancing neighborhood resilience.

Introduction

The increasing frequency and intensity of extreme weather events and resulting power outages highlight vulnerabilities in our aging utility infrastructure. In July 2024, Hurricane Beryl left nearly 1.7 million people without power for three days.¹ Similarly, a Public Safety Power Shutoff in 2019 to limit the damages from a California wildfire affected 2 million customers and resulted in more than \$2 billion in economic losses (Fuller 2019). At the same time, utilities are facing exponential electric growth driven by ongoing electrification efforts and the expansion of energy intensive sectors (such as data centers), weaknesses in the distribution system, and planned retirement of fossil fuel plants. Therefore, it is imperative for utilities to prioritize proactive resilience investments—including demand-side management (DSM) programs for existing buildings that make them more energy efficient and operationally resilient—so that they can meet growing demands for energy.

A 2024 ACEEE report discussed DSM solutions for existing buildings and how they improve a facility's energy performance to enhance building and grid resilience, offering a cost-effective, low-emissions alternative to fossil fuel generators (Srivastava, Garfunkel, and Wood 2024). DSM solutions help maintain habitable conditions during outages. For example, insulation upgrades, customer-sited battery storage, and distributed generation can enable building occupants to withstand the adverse effects of a loss of power—thereby providing resilience. The benefits extend to the community, as buildings with these upgrades operate more efficiently while retaining comfortable and safe conditions during extreme events. However, this collective impact on a neighborhood scale remains undervalued.

Building-level upgrades are important, but their combined impact at a neighborhood scale can more effectively address risks from extreme weather. This report examines how utilities currently value resilience and proposes a method to estimate benefits at the neighborhood scale for program planning and screening decisions. Because there are no standard metrics for valuing resilience, such metrics vary based on the extreme event, building types, climate zone, and individual and community needs (EPRI 2023; Specian et al. 2020). We use an approach to valuing resilience that considers lower peak demand, reduction in outage hours, and decreased interruption costs at the neighborhood scale, combining direct building and grid impacts that utilities and policymakers can use in their cost-benefit analyses and planning decisions. Finally, we discuss ways to improve resilience valuation methods.

Valuing the resilience benefits in cost-benefit analyses can help advance building retrofit program investments. The amount spent on measures with resilience benefits—and how much customers can afford (or are willing to pay)—is dependent on the cost of measures and the level of resilience provided. This information on program-level resilience impacts can act as a benchmark that utilities and regulators can compare against to evaluate prospective measures, helping improve the program screening and grid planning processes.

Defining neighborhood resilience

Resilience is commonly defined as the ability to adapt to, withstand, and recover from major events (FERC 2018; NGA/NASEO 2021). Resilience is generally defined in relation to severe, long-term events that can cause power outages and is centered on critical services—both elements that differentiate resilience from reliability (NESP 2024). With respect to the buildings sector, these events can include

¹ *The Guardian*, "[Hurricane Beryl leaves 1.7m people in Texas without power amid extreme heat](#)," July 10, 2024.

physical threats from extreme temperatures, fire, earthquakes, fuel disruptions, equipment failure, vandalism, and terrorist and cyber-attacks (Specian et al. 2020).

A 2024 ACEEE report explored the resilience benefits at the individual building level from DSM solutions and highlighted the technologies that enhance them (Srivastava, Garfunkel, and Wood 2024). Because resilience benefits accrue to the building occupants, to communities where measures are implemented in municipal buildings, and to the energy systems, they are “hyperlocal” (Twitchell et al. 2020). Research has found that utility energy storage programs offer benefits to customers and the grid, and that identifying resilience investments through a localized approach optimizes benefits to both (Twitchell et al. 2020).

For utilities and policymakers to value resilience benefits from building investments at a local level, it is necessary to first define the boundary of the evaluated area based on interactions of buildings within the area. Our research identifies three approaches for defining the focus area: a neighborhood served by a congested utility feeder or substation with known outage instances; a neighborhood with vulnerable populations (e.g., elderly customers, customers with medical needs or limited mobility); and areas with low customer participation in utility programs.

Within the utility sector, reliability and resilience are often assessed at the feeder level. Feeders are circuits that bring power from substations to transformers closer to customer sites (DOE 2023). Utilities use feeder capacity to assess a system’s ability to meet projected load growth (Rylander and Krupp 2024). In a planning pilot, the Electric Power Research Institute (EPRI) and Tennessee Valley Authority (TVA) used the wide-area distribution assessment (WADA) method for capacity and resilience planning (Rylander and Krupp 2024). The WADA method evaluates the capacity of each feeder to meet projected load growth. Based on the results, EPRI and TVA identified the highest-priority feeders requiring interventions such as energy efficiency, distributed energy resources (DERs), and wire upgrades to increase feeder resilience to extreme weather, thereby enhancing customer, building, and grid resilience in targeted neighborhoods.

Neighborhood resilience is especially important in areas with vulnerable populations likely to face severe impacts from extreme weather events. Oak Ridge National Laboratory; the University of Tennessee, Knoxville; and the U.S. Department of Energy (DOE) Building Technologies Office developed an energy burden and thermal resilience planning framework to inform the location of thermal energy storage systems to increase community-level resilience in disadvantaged communities (Shen et al. 2024). The framework assesses household energy burden and thermal resilience by evaluating the impact of building-level thermal energy storage systems on reducing energy burden and improving thermal resilience. It incorporates community-level planning to maximize resilience benefits (Shen et al. 2024).

Some utilities use customer willingness to participate in proposed programs to plan their building energy resilience investments in those programs. Customers who have not previously adopted energy efficiency measures may be more interested in programs that offer clearly communicated individual customer and neighborhood resilience benefits. These programs by extension enhance the overall resilience of the electric grid. Efficiency Vermont has included customer resilience needs in their energy efficiency programs, adapting energy efficiency investments to enhance resilience according to the customer’s specific requirements (Capps 2024). Efficiency Vermont is evaluating the value of the resilience benefits for both the customer and the grid by prioritizing the customer-specific resilience benefits of energy efficiency (Capps 2024).

Utilities need to convey neighborhood resilience value

Although resilience benefits are localized, few utilities track or quantify the building energy resilience benefits from their efficiency investments at the neighborhood level to understand the aggregated impacts on customer costs, savings, reliability, and safety. In the cost-benefit tests used to assess both the cost effectiveness of utility investments in energy efficiency and the benefits of those investments for customers, utility systems, and society at large, resilience benefits are rarely recognized as applicable. They are largely not captured due to the lack of established methods for valuing resilience (Srivastava, Garfunkel, and Wood 2024). Existing methodologies focus on either benefits to individual residential or commercial building customers or benefits to the grid. It is difficult to adapt these approaches to assess the resilience benefits from a large group of buildings in a geographical area (Kontokosta and Malik 2018; Clendenning et al. 2024; Apex Analytics 2022; NREL 2022).

To assess the value of resilience benefits from their energy efficiency program investments at the building level, utilities consider an individual customer’s willingness to pay for the investment or the cost of avoided alternative investments. These benefits are tracked as nonenergy impacts of the programs. Table 1 shows various approaches to valuing resilience benefits.

Table 1. Approaches to valuing building customer resilience benefits

Approaches	Valuation method	Examples
Value of lost load (VoLL)	Calculates the value of resilience as the amount a customer is willing to pay to avoid a service disruption and is usually expressed in \$/kWh or \$/MWh; can be used to value an energy efficiency investment’s ability to provide electricity during an outage and benefits to the building occupants or owner	Lawrence Berkeley National Laboratory’s ICE calculator; American Public Power Association’s eReliability tracker; Central Maine Power; EPB Chattanooga and Oak Ridge National Laboratory study
Willingness to pay (WTP)	Willingness to pay for an individual energy system to avoid the consequences of disruptive events is used as a proxy value for resilience; can be aggregated and normalized at the community level	EPRI’s Modular Template Framework and Resilience Value Extraction Tool
Avoided costs	Value of resilience from a customer’s perspective in relation to energy efficiency investments as an alternative to investment in backup power	Apex Analytics’ resilience valuation tool for the Northwest Power and Conservation Council; Federal Energy Management Program’s Customer Damage Function (CDF) Calculator to estimate avoided costs associated with resilience investments

Resilience is not well defined in formal utility regulatory proceedings. While state policymakers and utilities are increasingly prioritizing resilience policies and programs—including investments in resilient DERs—as part of their clean energy programs or grid modernization efforts, not many are adequately quantifying the value of improved resilience and are missing an opportunity to account for the benefits (Olinsky-Paul 2015; Converge Strategies 2019). When setting their performance targets or long-term capacity planning efforts, a few utilities consider the utility system resilience benefits captured in the

avoided transmission and distribution costs from their investments at the grid level. They achieve this by recognizing the reliability and resilience benefits of energy efficiency measures and investments in grid infrastructure, though they do not quantify these benefits financially (Kallay et al. 2021). Table 2 shows examples of the few utilities and industry stakeholders who are starting to value resilience benefits.

Table 2. Existing approaches to valuing systemwide grid-level resilience benefits

Approaches	Valuation method	Example
Utility performance incentive mechanism (PIM) resilience metrics	Includes incentive structures for performance targets based on traditional measures of systemwide reliability and metrics to assess reliability and resilience investments	Commonwealth Edison (ComEd) and Ameren’s reliability and resilience PIMs (RMI 2024)
Long-term capacity planning	Incorporates extreme event impacts and resilience investments into utilities’ long-term capacity planning and forecasting	TVA and EPRI integrated resource planning pilot with the WADA method; NYSERDA’s <i>Impacts of Climate Change on the New York Energy System</i>
Optimal community-level resilience planning	Optimizing resilience benefits at community level to reduce energy burden and increase resilience for disadvantaged communities	Oak Ridge National Laboratory/University of Tennessee, Knoxville analysis

While there are existing resilience valuation approaches, most do not allow a simultaneous evaluation of resilience benefits on the neighborhood scale and on the grid. Therefore, an accessible approach is needed that decision-makers can use to assess resilience benefits at a scale that bridges the gap between building customer-level and grid-level valuation.

An Approach to Value Neighborhood Resilience Benefits

Severe weather events and rising demand for electric power due to ongoing electrification efforts—coupled with expansion of energy intensive sectors, such as data centers and manufacturing facilities—have reversed a long period of flat electricity demand that began in 2007. With data center growth expected—to continue to accommodate generative artificial intelligence (AI) and other uses—energy efficiency is key to ensuring grid reliability, avoiding power outages, and improving the resilience of homes and commercial buildings. Since the 1970s, DSM programs have effectively helped meet demand growth and keep customer rates affordable. These programs include strategies to reduce and efficiently use electricity, providing resilience benefits during times of peak demand. Quantifying this value at a localized level can improve program investment. However, there are no standard processes to determine this value; the approaches in tables 1 and 2 involve complex calculations of the energy use, risks, damages, and survey of user preferences. Consequently, they are unlikely to be adopted at scale.

In this report, we assess resilience value at the local neighborhood scale from building energy upgrades, considering both compensable grid and building benefits. This approach captures the interrelated factors of energy use based on recent weather data and the impacts of energy efficiency and electrification upgrades for a location with a mix of commercial and residential buildings. Such a method can help utilities compare building energy retrofit investment costs with the level of resilience provided; it can also help them assess ways to offset the cost of resilience investments in a cost-benefit analysis.

We illustrate our approach using actual meteorological weather data and the U.S. Census Bureau's Public Use Microdata Areas (PUMA)² level energy use and utility data for southeast Westchester County, New York. Although a neighborhood is typically smaller than a PUMA, we use the PUMA as a representative for the neighborhood due to the granularity of data available to us. Our reasons for selecting this region included the state's goals to accelerate energy efficiency, reduce greenhouse gas emissions, and decrease consumer energy costs, and the availability of historic and forecast data around energy use, weather, and utility distribution capacity. Southeast Westchester has a mix of households and businesses that reflect the diversity of buildings in a typical urban-suburban region; it includes six towns with a total population of 120,175 in 2018. In 2018, the area had 39,630 households and, as of 2017, approximately 4,094 businesses. We compute the value of resilience using four steps: (1) assess the extreme event using actual weather data; (2) identify the type of neighborhood to focus on with a mix of buildings that is vulnerable to the extreme event; (3) analyze the neighborhood energy use and the impact of efficiency measures that provide resilience benefits; and (4) quantify neighborhood resilience benefits.

Assessing critical climate events or threats

Since 1980, the number of disaster events attributed to occurrences of unusually severe weather or climate events has increased; in 2024, 27 events were reported in which overall damages reached or exceeded \$1 billion (NOAA National Centers for Environmental Information 2024). Changing climate conditions are projected to increase the frequency and intensity of extreme weather events,³ including significant changes in annual average temperatures relative to historical conditions, leading to more extreme heat days (Dahl et al. 2019), increased snowfall, and severe storms (figure 1), all of which will affect building energy consumption and power grids. The extreme weather events will likely increase peak-time building energy use for heating or cooling, cause power outages lasting days or weeks (Hachem-Vermette and Yadav 2023), and potentially make outages more dangerous. Power outages can also be caused by hurricanes, flooding, and wildfires; however, these events represent a different level of disruption (e.g., damage to structural components and community displacement) and require many adaptation and mitigation measures in addition to energy efficiency. Therefore, we have not focused on these events in this study.

² PUMAs are nonoverlapping, statistical geographical areas that divide each data or equivalent entity into geographical areas containing at least 100,000 people. New PUMAs are created after the completion of the decennial census, as the population counts and census tracts are critical inputs in the process.

³ Extreme weather in the context of this report is defined using impact-related thresholds to determine if an event is extreme. The thresholds are location specific. For example, a threshold might be the number of consecutive days over 100°F, which can be used to quantify heat waves, but the impacts associated with this threshold will vary according to the location.

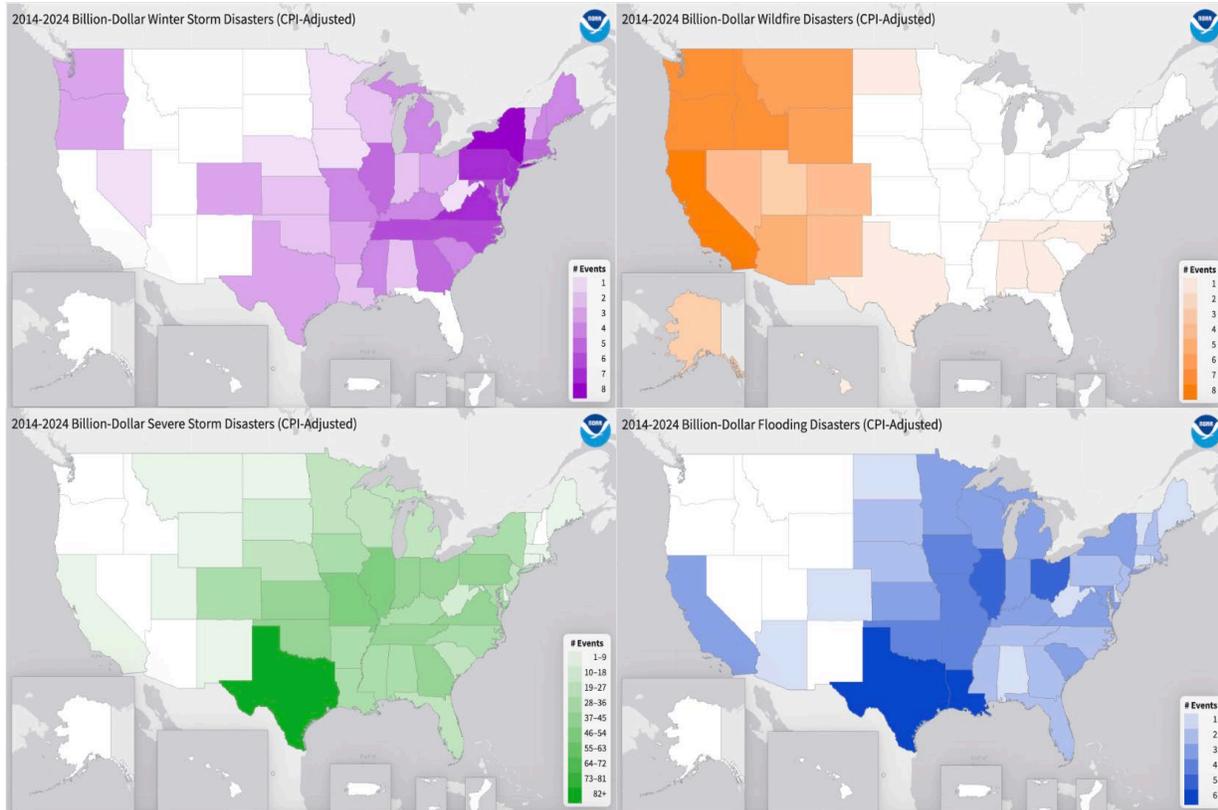


Figure 1. Variation in extreme weather and climate events across the country. Source: NOAA National Centers for Environmental Information 2025.

The impacts of extreme events and the associated costs vary geographically across the country. A utility's vulnerability to those events and the actions it can take to mitigate risks depend on several factors, including the region where it is located and the grid infrastructure (Bruzgul and Weisenfeld 2021; McCurry and Nethercutt 2022); stakeholders who are impacted; and available funding for proactive resilience investments. Therefore, potential resilience investments vary across the country, but common resilience-related approaches—such as existing building energy efficiency programs—can reduce the impact of weather-related events.

Studies on climate impacts on the power sector and mandated Public Service Commission utility-scale resilience plans that examine adaptation and mitigation strategies are tools that can assist utilities in identifying their vulnerabilities and reducing risks. For example, the 2024 *New York State Climate Impacts Assessment* discusses the impacts of extreme weather events such as extreme heat, precipitation pattern changes, and increases in storm intensity on the electrical transmission and distribution systems. Because New York's annual average temperature is projected to increase throughout this century (figure 2), extreme heat events can increase building energy demand (due to greater use of air-conditioning) and reduce the utility transmission capacities (due to hotter power lines), risking interruptions to electric power supply (Meier et al. 2024). The state's assessment highlights the importance of energy system planning to evaluate climate impacts, changes in energy demand, and measures necessary to maintain system resilience.

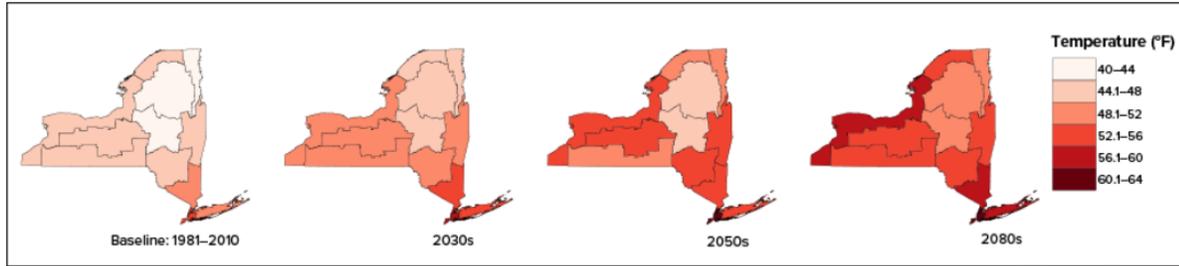


Figure 2. New York State Climate Impacts Assessment projections of annual average temperature through the 2080s. Source: Meier et al. 2024.

To help prioritize investments, some utilities already assess the vulnerability of their infrastructure and operations as part of either their resilience plan filing requirements for state regulators or their integrated resource plans.⁴ The analysis can help identify where the major substations or transmission lines are coincident with a hazard based on available climate information. For example, Seattle City Light and the Consolidated Edison Company (Con Edison) have developed a climate vulnerability assessment to determine which events are likely and require adaptation actions. An understanding of the ways in which climate-event-induced disruptions impact energy use can inform utility investments with resilience benefits.

Con Edison's 2023 *Climate Change Vulnerability Study* identifies strategies to mitigate and respond to key climate impacts in its service territory. These risks include rising temperatures, coincident high heat and humidity, flooding, wind and ice, and extreme events such as hurricanes and heat waves (ConEd 2023). By 2050, Con Edison expects up to 32 days annually with maximum daily temperatures over 95°F, leading to an increase in electric demand (ConEd 2023). ConEd is incorporating these projections into its reliability planning, including customer-side measures such as energy efficiency and demand response.

To illustrate how extreme weather events impact electricity use in our study area of southeast Westchester, we compared the neighborhood energy model using publicly available average weather from 1976–2005 (NREL's Typical Meteorological Year [TMY] weather data) to a model using the 2018 weather (NREL's Actual Meteorological Year [AMY 2018] weather data).⁵ The weather files include information on ambient temperature and other weather that impacts the total energy consumed for heating and cooling. Figure 3 shows the simulated results and highlights the variations in building energy use under the average weather using TMY data and actual 2018 weather.

Based on the available data, the annual electricity demand in neighborhood buildings increases during the summer and sometimes in winter under the actual 2018 weather data. This difference is due to variability in weather that is not captured in the 30-year average data in the TMY files, as well as to hotter summers and polar vortex events caused by extreme weather events. Building energy analyses usually relies on TMY data and can underestimate the benefits of energy efficiency and demand flexibility. Therefore, comparing energy use under TMY and AMY data provides valuable insights when we bridge efficiency and resilience benefits. Few studies have examined how the uncertainty in local

⁴ Between 2022 to 2024, at least 30 utilities filed one or more resilience plans to improve grid resilience (Schellenberg and Schwartz 2024).

⁵ AMY files are the actual weather datasets that have been collected over a given year. A TMY file for a location is developed using 15–30 years of hourly weather data for that specific location, and it is assumed to be representative of the average climatic conditions (Marion and Urban 1995). ResStock and ComStock provide only load shapes associated with weather files for a TMY3 and AMY2018 weather year. Given data availability at the time of analysis, we used AMY 2018 data for this analysis.

weather conditions affect building energy use, emphasizing the need to consider weather variability in forecasting energy performance (Azimi and Baltazar 2024; Wang et al. 2012; Hong et al. 2013; Kneifel and O’Rear 2016).

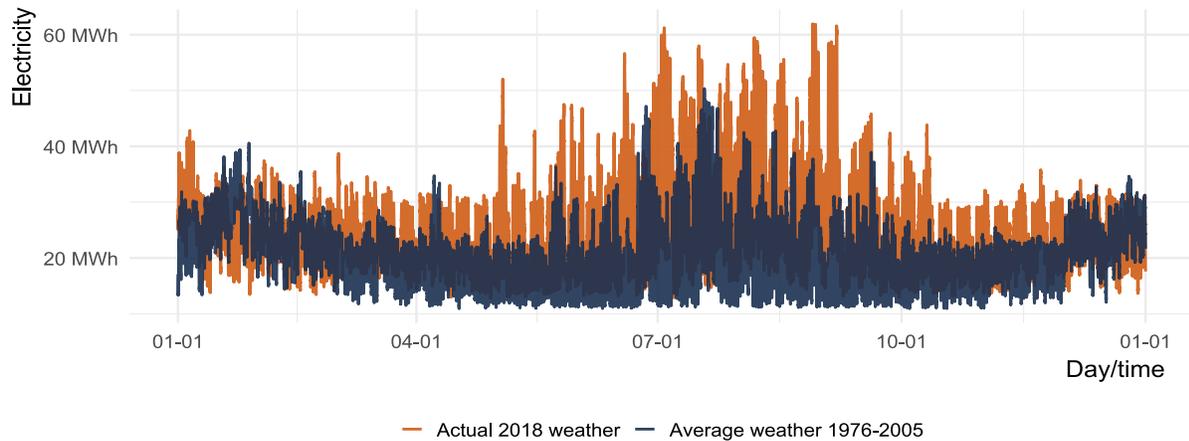


Figure 3. Full-year AMY18 versus TMY3 data showing increase in electricity use

Identifying the neighborhood with a mix of vulnerable buildings

Building retrofits offer localized benefits, which can make the electric grid and building customers more resilient against extreme events. Depending on the location, energy efficiency measures offer different types of benefits—resilience at a community building or shelter facility provides systemwide benefits, whereas resilience at an industrial center may benefit only a smaller group of customers. A localized approach to valuing the resilience benefits is therefore critical to optimizing the impacts and prioritizing investments (Twitchell et al. 2020; Carvallo, Frick, and Schwartz 2022).

The first step is to define the geographical boundary for the study area based on the interactions of the area’s buildings. Based on our review of the literature and interviews of utility program administrators, the area is selected based on having one or more of three characteristics: a location with congested feeders, a region with disadvantaged communities or individuals in vulnerable situations, or an area with low utility program uptake. Census tract data can help define the boundary for the analysis.

A detailed assessment of a given study area can help utilities quantify risks related to extreme weather and prioritize resilience investments that are best suited for a region, helping move efforts in a focused and cost-effective way (Bruzgul and Weisenfeld 2021). For example, an energy modeling and forecasting study on the impact of heat waves on the grid in Los Angeles County found that electricity consumption in residential and commercial sectors may rise by 0.2–6.5 GWh (2–51%) by 2060 depending on population growth, building efficiency, air-conditioning efficiency, and warming temperatures (Burillo et al. 2018). The results inform recommendations for increasing system capacity and implementing energy efficiency measures to meet the loads under future temperature changes. Utilities can use such analysis to understand the impacts of low-frequency and high-impact events and evaluate the energy efficiency measures and actions that can help maintain operations and reduce the effects of extreme events.

To demonstrate our approach, we defined the boundary of our study area—a southeast Westchester neighborhood—using publicly available PUMA data at the time of the analysis and substation data from utility hosting capacity maps. In our analysis, we stipulated maximum load in feeders nearing capacity for actual capacity to explore what resilience benefits utilities accrue from energy efficiency investments. In defining a study area for resilience analysis, utilities can use real feeder data from areas

that are capacity constrained and reflect regions that are likely to see load growth due to increases in population, extreme weather events, electrification, and use of electric vehicles.

We used ConEd’s hosting capacity maps, which help identify DER locations and sites for private generation and interconnection of resources (ConEd 2025). We computed the substation capacity for the study area by overlaying Con Edison’s feeder-level geographic information system (GIS) data with the 2010 census PUMA region. Figure 4 shows feeder lines in the study area, with the feeder demand data aggregated at the substation level. This provided an average substation peak of 224 MW in the area.⁶ Given the publicly available data, we used the substation peak to approximate the hosting capacity in our analysis.

Data needs and tools

Data needs: PUMA-level energy use and climate data to understand the neighborhood energy use, grid-related substation, or feeder-level hosting capacity

Tools: U.S. Census Bureau TIGER/Line Shapefiles, GIS

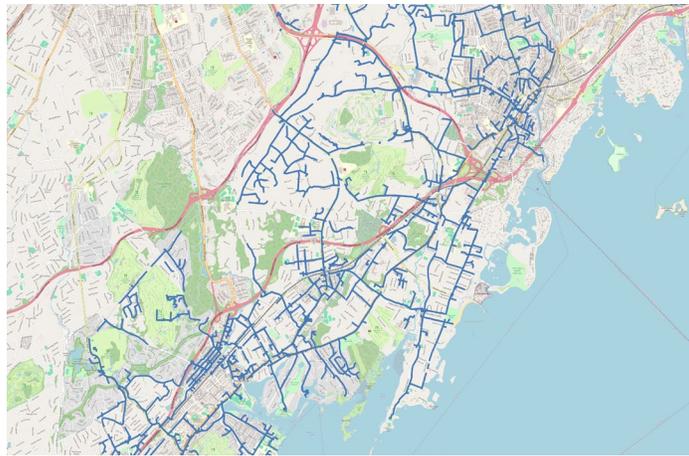


Figure 4. Map of Con Edison feeder lines for the southeast Westchester PUMA region. Municipalities in the study area include Rye City, Mamaroneck Village, Harrison Village, and Port Chester Village.

Analyzing neighborhood energy use to value resilience benefits

Weather changes can result in building electric load increases that may exceed utility capacity to meet them and cause possible interruptions to electric power supply. Further, the growing market share of technologies and appliances such as electric vehicles, energy storage, and heat pumps, which are driven in part by initiatives to reduce greenhouse gas emissions, can further increase a neighborhood’s electricity use. Given that building heating and cooling demand is particularly sensitive to outdoor temperature and has a significant impact on overall building electricity demand during an extreme event, it is critical to understand existing loads and investigate ways to reduce them.

⁶ To model a distribution feeder nearing hosting capacity, we take a real feeder and use the maximum that the distribution feeder can bear as the proxy for the load it can carry and calculate the average value at the substation level.

The New York Climate Action Plan has set a commitment of net zero emissions statewide by 2050, with 85% of residential and commercial buildings electrified by 2050 (NYS Climate Action Council 2022). Between 2021 and 2050, the New York Independent System Operator (NYISO) predicts baseline electricity energy demand will increase by up to 31% (Meier et al. 2024; NYISO 2022). By midway through the 2030s, electrification will change New York State’s electric demand from summer-peaking to winter-peaking (NYISO 2023).

Determining the neighborhood baseline energy load profile can give decision-makers insight into the existing infrastructure and its ability to meet current and projected growth in electric loads. Utilities and policymakers can use the neighborhood baseline energy use for the different end uses to assess the impacts associated with inaction or incremental investments in energy efficiency that offer resilience benefits.

For our southeast Westchester analysis, we modeled the neighborhood electricity demand for the baseline building stock comprising residential and commercial buildings, as well as the baseline building stock retrofitted with energy efficiency and electrification packages. We studied the impact of actual weather data on neighborhood energy use for the baseline building stock and the baseline building stock with 30% of the buildings retrofitted with an electrification upgrade. We assumed a moderate rate of electrification for the neighborhood buildings, as heat pump adoption in cold climates is increasing due to both the improvements in efficiency and efforts to reduce adoption barriers through programs and incentives (Nadel 2023; Baxter and Groll 2017; Mai et al. 2018). Additionally, New York State’s 2050 vision for the building sector includes plans for 85% of homes and commercial building space statewide to be electrified using a combination of energy-efficient heat pump technologies and thermal energy networks (NYS Climate Action Council 2022). Furthermore, some buildings will undergo electrification to gain additional benefits, such as adding cooling where previously unavailable, while others may not pursue it due to the associated cost increases.

The residential and commercial building energy demands were modeled using the National Renewable Energy Laboratory (NREL) ResStock dataset 2022.1 Release and ComStock dataset 2023 Release 2.⁷ ResStock and ComStock generate representative residential and commercial building stock samples based on multiple data sources, including the Residential Energy Consumption Survey, the Commercial Buildings Energy Consumption Survey, and hundreds of individual energy simulations using EnergyPlus and OpenStudio that are statistically representative of the building stock.

Data needs and tools

Data: end-use load profiles for commercial and residential buildings at the PUMA level and AMY18 weather data to estimate baseline and growth in consumption

Tools: ResStock and ComStock end-use load shapes and savings shapes

To model the baseline neighborhood energy demand, we added together the commercial and residential load profiles for southeast Westchester County.⁸ We used 15-minute time series for pre-

⁷ NREL’s ResStock and ComStock tools help states, municipalities, utilities, and others understand which building improvements save energy. ResStock includes single- and multifamily homes including mobile homes and high-rise apartments. ComStock represents 14 commercial building types covering 65% of commercial floor area (small, medium, and large office buildings; retail buildings; strip malls; warehouses; primary and secondary schools; full- and quick-service restaurants; small and large hotels; hospitals; and outpatient care facilities).

⁸ Our approach likely underestimates neighborhood-scale energy use as it does not include large commercial and industrial facilities.

aggregated end-use load profiles and measured impact profiles (also known as end-use savings shapes)⁹ for the whole year for the evaluated area (downloadable from the web viewers at <https://resstock.nrel.gov/datasets> and <https://comstock.nrel.gov/page/datasets>). We discuss the results for peak summer and winter months. Past studies and approaches have relied on a combination of data sources, simplifications to model the building stock energy use, and limited geographic coverage to map building energy efficiency scenarios and extreme weather days to an electric system load, to assess their impact on reducing energy consumption and shaving peak demand for a region (Landsman et al. 2024; Specian, Cohn, and York 2021). However, our goal was to simplify the process of aggregating building energy-use profiles for the neighborhood building stock and use existing granular datasets—such as the ResStock and ComStock models and actual weather data—to estimate the resilience benefits.

We scaled the residential measure impact profiles for energy efficiency and whole-home electrification for New York State by the percentage of the population in Westchester County because the end-use savings shape is not published at the PUMA level. The commercial building energy efficiency and electrification packages are available at the PUMA level and include two common types of HVAC systems—heat pump rooftop units (RTUs) and boilers with heat pumps. The heat pump RTU is for buildings with gas or electric RTUs, while the air-source heat pump boiler replacement is for buildings with existing boiler systems. Appendix A has more details on the packages used in our analysis. Dual-fuel (hybrid) heat pumps and energy storage are proposed as solutions to support the energy transition by mitigating grid impacts from electrification and lowering high electric heating costs in very cold conditions (Landsman 2024; Margolies 2022; Massie and Schwartz 2023). We did not include these technologies in our analysis, but they could be similarly analyzed in the future.

Results from the neighborhood electrification analysis showed that during cold winter days, buildings retrofitted with heat pumps increase the electric demand due to the growth in electric heating, while it is lower relative to the baseline scenario for the rest of the year. The increase in winter electric demand results in a dual peaking system instead of a summer peaking one. Based on the modeled data, the magnitude of winter peak loads in January and February are almost doubled at times due to the diminishing heat pump efficiency and the use of backup electric resistance when the mean outdoor temperatures are lower (Present et al. 2024; CaraDonna, Parker, and Meyer 2024).¹⁰ However, recent technological advancement has improved heat pump efficiency and performance in cold climates. Heat pumps in our model—that is, ducted systems with seasonal energy efficiency ratio (SEER) 24 and ductless systems with SEER 29.3 in ResStock buildings, and variable speed RTUs with a full-load COP of 3.6 and integrated energy efficiency ratio above 17 in ComStock buildings—also provide a more efficient form of cooling than conventional air-conditioning. As a result, between the months of May and September, the electric demand in the electrification scenario is slightly lower (see figure 5).

⁹ An end-use savings shape is the difference in energy consumption between a baseline building and a building with an energy efficiency, electrification, or demand flexibility upgrade. It results in a time-series profile that is broken down by end use and fuel (electricity or on-site gas, propane, or fuel oil use) at each time step.

¹⁰ All modeled heat pumps have supplemental backup heating. In the measure packages used for this report, the supplemental backup heating is electric resistance. ResStock and ComStock also model measure packages in which the existing fuel-fired system is retained as the backup heating source, but this was not used in our report. The backup system turns on in ResStock when the heat pump cannot meet the full heating load and the outdoor temperature is between 5°F and 40°F (Present et al. 2024). The minimum temperature for compressor operation for ComStock heat pump systems is 17°F for packaged terminal heat pumps and 10°F for packaged single zone heat pumps (CaraDonna, Parker, and Meyer 2024).

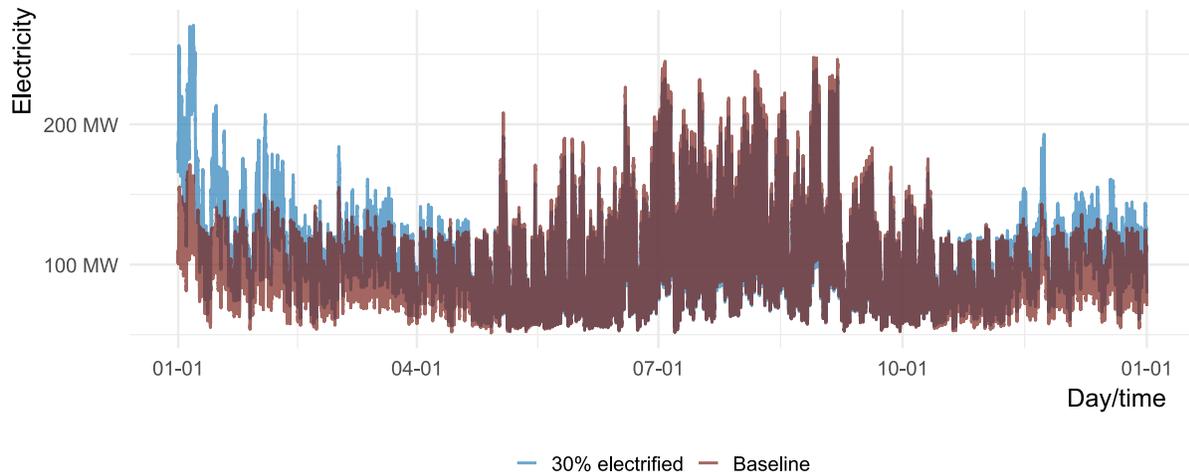


Figure 5. Peak loads are higher in winter months and slightly lower in summer months under the electrification scenario compared to baseline with the existing building stock

Building energy efficiency solutions reduce peak demand

Because energy efficiency measures such as upgrades to building envelope insulation are critical to managing the impacts of electrification on system demand, we modeled an electrification plus envelope upgrade scenario to reflect investments in the building shell. Energy efficiency measures help minimize building loads under electrification, reduce required equipment capacities, and avoid electrical infrastructure upgrades while also improving the building's thermal and electrical resilience (ACEEE 2023; Hledik et al. 2021; Jones et al. 2023). In the absence of these investments, there will be an increase in electric demand. To simulate the envelope and electrification upgrades, we used the ResStock measure impact profiles for a basic envelope upgrade and whole-home electrification and a combination of ComStock envelope upgrades (wall and roof insulation, and new windows)¹¹ and an electrification package for commercial buildings.

Figure 6 shows the simulated results for southeast Westchester. The results indicate that electrifying 30% of the neighborhood building stock increased peak demand during the heating season and lowered daily peak demand during the cooling season due to improvements in cooling efficiency, compared to the baseline peak demand with no building energy efficiency investments. However, pairing building envelope upgrades with electrification measures consistently lowered the winter and summer system peaks compared to when only building electrification measures are implemented. This illustrates the importance of investing in energy efficiency measures prior to electrification. The envelope measures reduced the overall energy demand, which is a building energy resilience benefit.

¹¹ This is the only high-efficiency envelope package available in ComStock. The upgrade package consists of three end-use savings shapes upgrades— window replacement, exterior wall insulation, and roof insulation. The upgrade package produces results by simulating interactions between the three measures. Depending on the applicability criteria, the package will upgrade window, wall, and roof thermal properties to align with those specified in ASHRAE's Advanced Energy Design Guide.

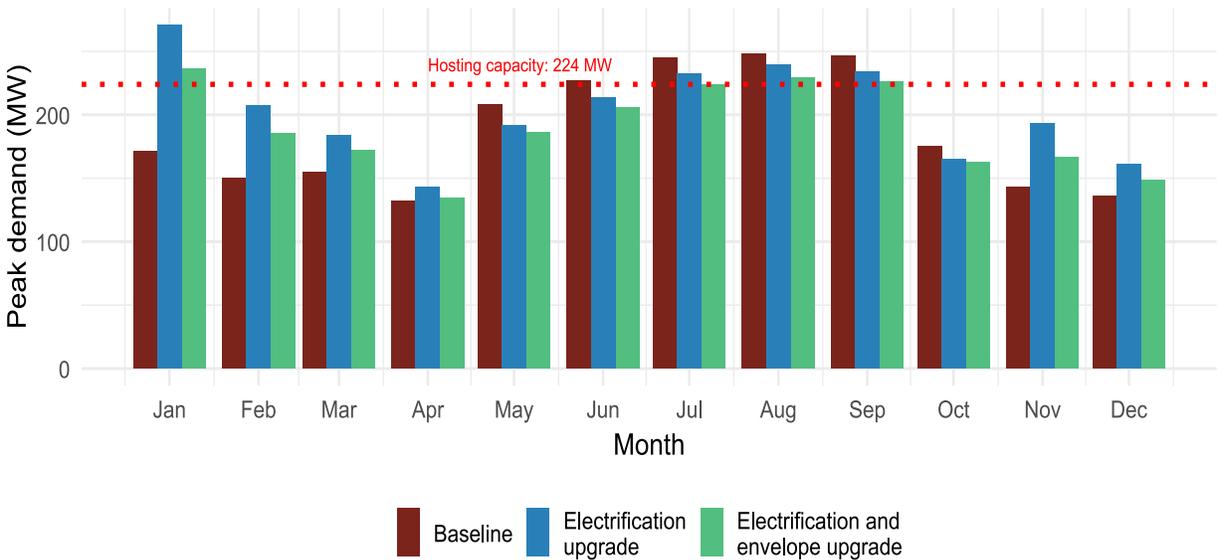


Figure 6. Comparison of Westchester neighborhood modeled peak demand under the electrification and electrification plus envelope scenarios

Quantifying neighborhood resilience benefits

While it is crucial to identify the location where resilience investments are needed, economic barriers must also be addressed to ensure the investments are cost effective. Unlike reliability standards that guide a utility and its regulators in making investments to address systemwide reliability deficiencies, there are no standards or other policy support for resilience investments (Twitchell et al. 2020). Since resilience is generally defined in relation to less frequent events that cause power outages, building retrofit measures providing resilience deliver their potential benefits within a relatively narrow window of time, limiting the opportunity to recover costs. Fortunately, the resilience measures offer other benefits, including energy cost savings for customers, reduced power generation pollution, improved comfort, and the ability to shelter in place during extreme temperature conditions. Thus, the measures offering resilience benefits provide multiple values throughout the year, and cost-effectiveness analyses should consider these nonenergy impacts.

The resilience investment decision includes an understanding of the costs (e.g., economic costs to the utility, value of lost load for different customers) of a short- and long-duration outage in the absence of an investment and the potential benefits of the target investment.¹² The resilience benefits—reduction in peak demand during periods of extreme grid stress, lower customer hours of outages, comfort and safety, and decrease in the economic costs associated with an outage—capture both the grid and customer values, and they can help orient the cost-benefit analyses and inform which measures offer an acceptable level of resilience and value.

¹² The tipping point at which resilience measures such as energy efficiency and flexible load management become cost effective depends on the duration of an outage. It is influenced by factors such as property loss and individuals in vulnerable conditions, including those with medical needs or limited mobility, and the elderly. Customers, utilities, and other stakeholders should collaborate to design investments that improve neighborhood resilience.

In our analysis, we computed three resilience benefits: lower peak demand, decrease in hours of customer outages, and the reduction in economic costs associated with an outage. We estimated the neighborhood resilience values under two scenarios: buildings with electrification upgrades, and buildings with envelope upgrades paired with electrification measures. To calculate the resilience benefits, we used 224 MW as the baseline substation hosting capacity, estimated through GIS analysis of publicly available substation data.

Data needs and tools

Data needs: 15-minute interval end-use load profiles and savings shape for commercial and residential buildings at the PUMA level; weather files; the number of residential and nonresidential customers; utility hosting capacity for the geographical area

Tools: R, R Studio

Peak demand reduction

Weather impacts the seasonal electricity demands and peak loads, and they remain highly dependent on investments in building energy efficiency measures (Wood et al. 2021). Our modeled scenarios used 2018 weather, which had a peak summer day in early September, and August as the hottest month overall. During August, the neighborhood baseline daily peak demand consistently exceeded the electrification daily peaks, and the baseline peak demand exceeded the utility hosting capacity on six days. As figure 7 shows, electrification measures paired with envelope upgrades had the lowest peak load, reducing the instances to three days when the summer peak demand exceeded the utility’s hosting capacity.

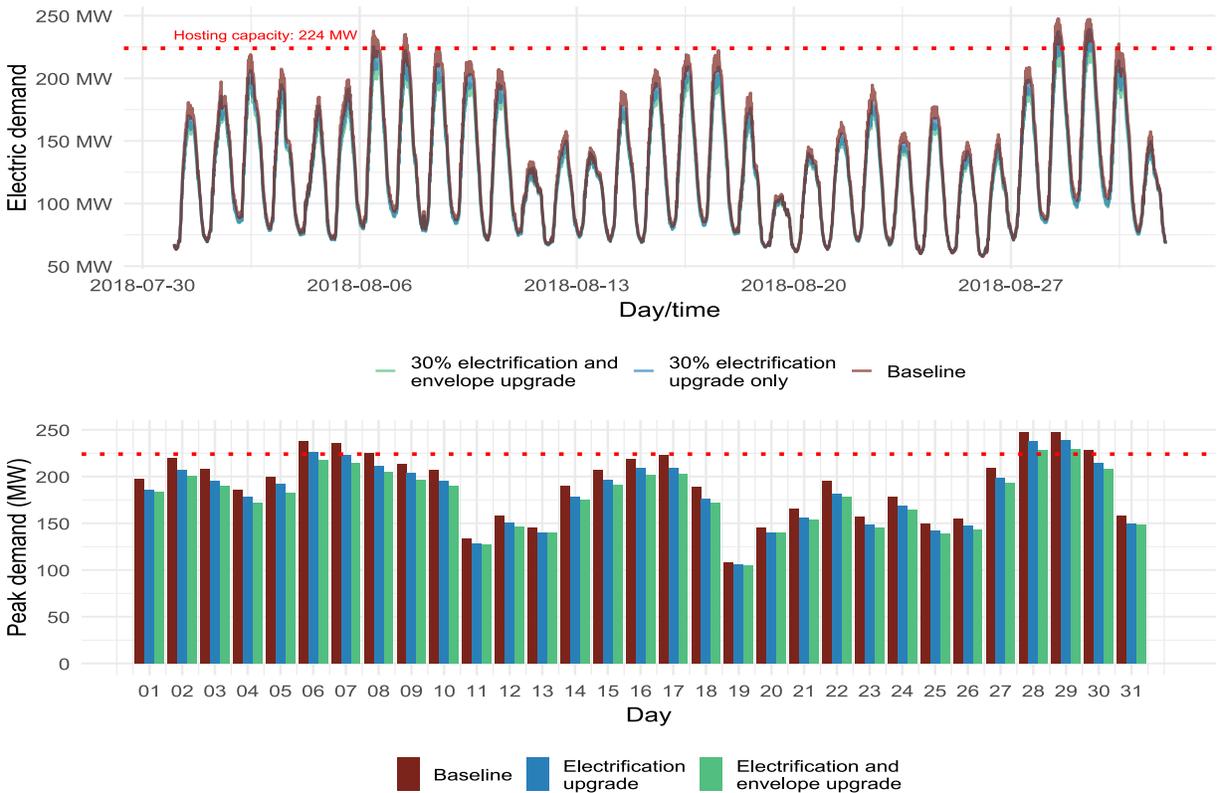


Figure 7. Comparison of daily peak demand for the summer month of August under a 30% electrification rate, electrification plus envelope upgrades, and a baseline of the existing building stock. The top graph shows 15-minute electricity consumption; the bottom graph shows daily peaks.

The neighborhood peak summer load was 246 MW on September 6 under the baseline scenario. The peak load is lowest under the combination of envelope and heat pump upgrades, proving again the ability of energy efficiency measures paired with electrification upgrades to reduce summer peak demand. This combination reduces peak summer load by 8%. As figure 8 shows, greater reduction is likely if 100% of the buildings are retrofitted with envelope and electrification upgrades. In reducing electric load, energy efficiency measures such as envelope upgrades improve resilience by reducing the likelihood of outages. Even when outages occur, tighter thermal envelopes can help occupants stay comfortable for longer if air-conditioning is unavailable. An additional advantage, particularly during the winter season, is that more-efficient building envelopes mitigate the risk of property damage and prevent pipes from freezing in the event of an outage.

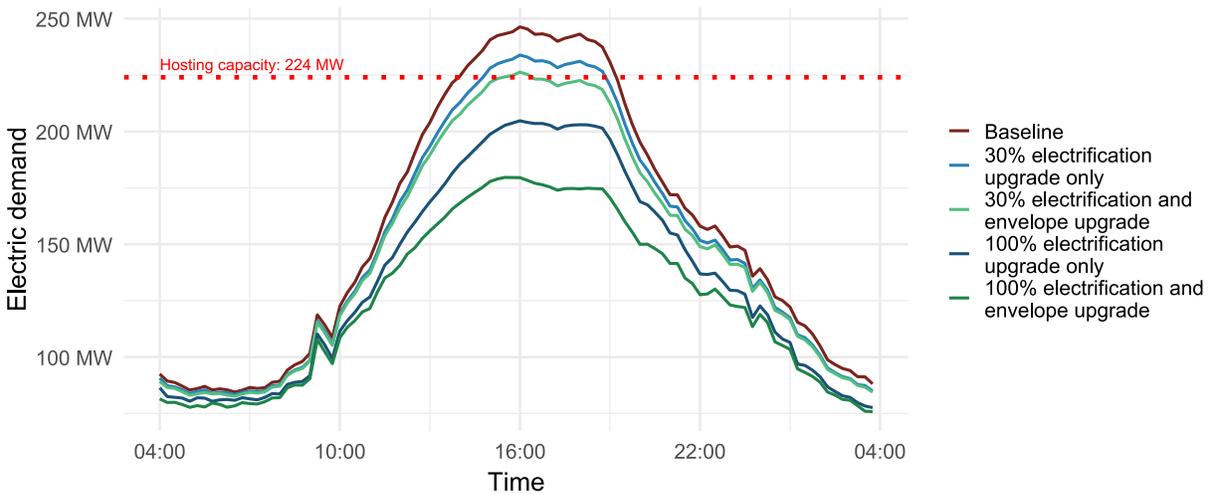


Figure 8. Retrofitting 30% of the neighborhood buildings in southeast Westchester with envelope and electrification upgrades reduces the peak load by 8% on September 6, which is the summer peak day

Because electrification moves the system electric demand from summer-peaking to winter-peaking, our models have peak demand occurring in January. As expected, during the peak winter month, electrification-driven winter peak loads are consistently higher than the baseline peak load under the 2018 weather data (see figure 9). The electric demand is highest when electrification measures are not paired with envelope upgrades, leading to some risk of outages on cold days with high heating demand.

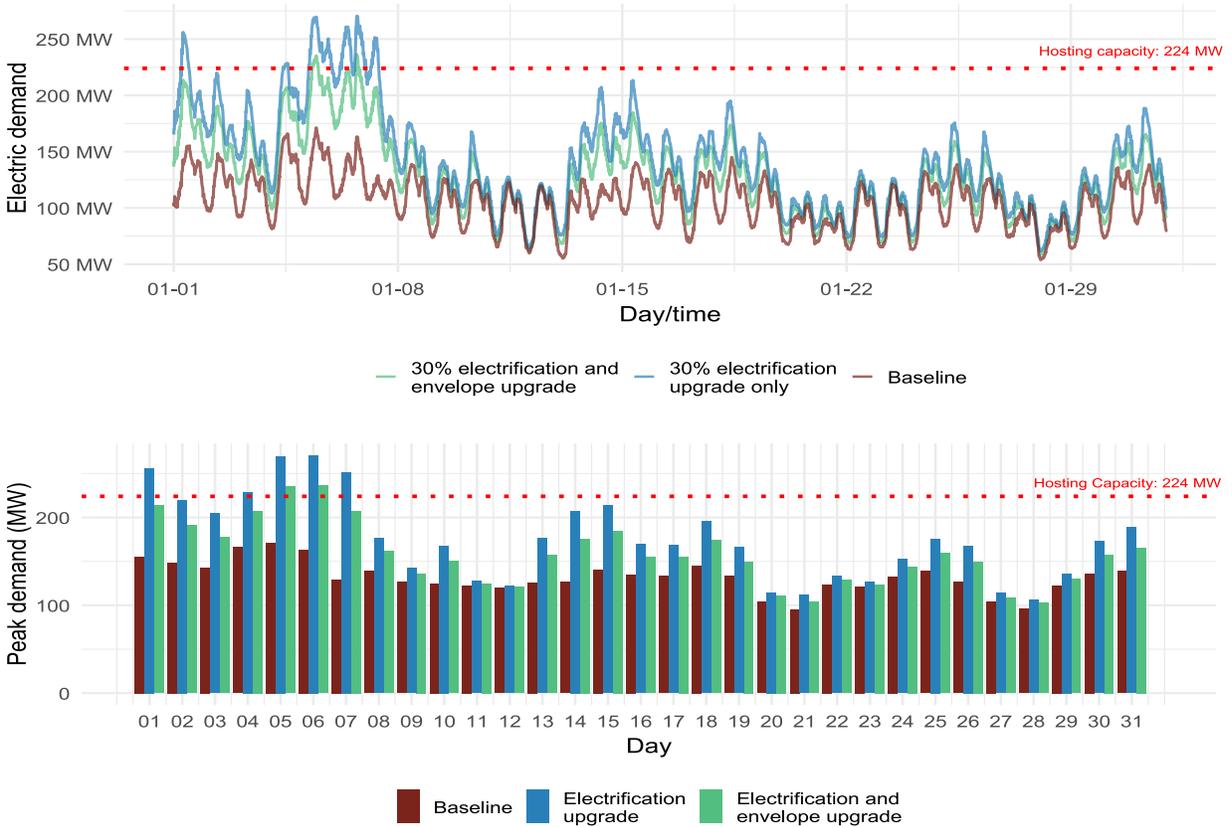


Figure 9. Peak loads in January under electrification, electrification plus envelope, and baseline scenarios. The top graph shows 15-minute electricity consumption. The bottom graph shows daily peaks.

The neighborhood winter peak load under the 30% electrification scenario was recorded as 270 MW on January 5. The winter peak is the highest when the building stock is electrified without upgrading the envelope. As figure 10 shows, electrifying 30% of the building stock with envelope and electrification upgrades reduced the peak load to below the utility’s hosting capacity, thus reducing the likelihood of an outage.

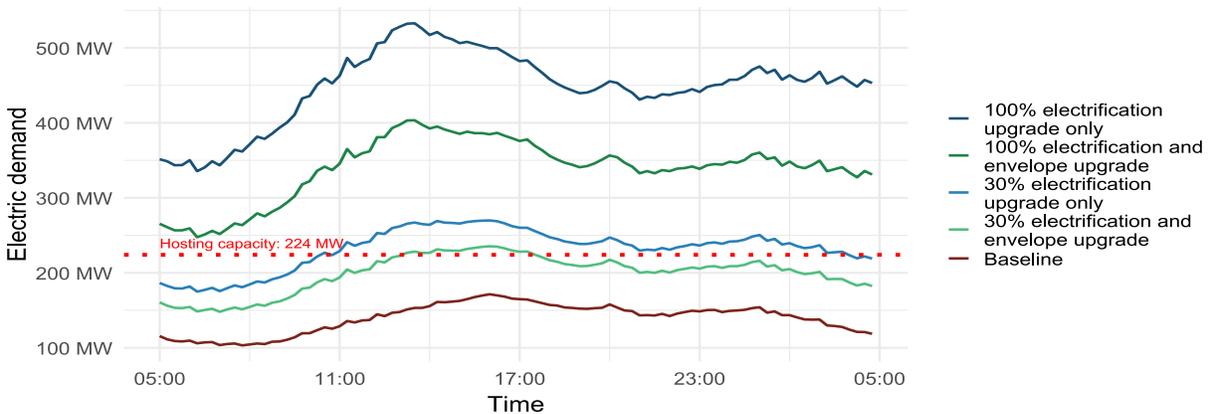


Figure 10. Retrofitting 30% of the building stock with envelope and electrification upgrades reduced the winter peak load to below the utility’s hosting capacity of 224 MW

Reduced cumulative customer-hours of outages

We examined how changes in electric demand under different energy efficiency measures impacted the total number of hours customers would be impacted by an outage during peak winter and summer months (see table 3). In January, under the electrification scenario, there were approximately 50 hours where peak demand exceeded the grid’s average hosting capacity (224 MW); this translated to approximately 7% of the January hours in which some customers might experience an outage if no load shedding occurred on the feeder. Pairing envelope upgrades with electrification reduced the number of hours where demand exceeded hosting capacity to 7 hours, or approximately 1% of hours in the month where some customers might experience an outage. This demonstrates the impact of energy efficiency measures on overall peak demand and the reduction of cumulative customer-hours of outages, allowing occupants to stay comfortable for longer.

In August, the hottest month, there were 20 hours of the actual weather data when the peak demand exceeded the grid’s hosting capacity under the electrification scenario (due to an increase in air-conditioning loads), signifying that some customers would experience an outage in the absence of demand response programs.¹³ However, building electrification measures helped reduce the hours that exceeded the grid hosting capacity to 8 hours, and pairing envelope retrofits with electrification lowered it to 3 hours (a reduction of 63%). While there is stress to the grid due to extreme temperature and electrification, energy efficiency measures such as envelope upgrades have a significant impact on reducing the potential cumulative customer-hours of outage.

Table 3. Cumulative customer hours of outages under 30% electrification scenario

Peak months	Baseline (AMY2018 data)	30% electrification	30% electrification + envelope upgrade
January	0	50	7
August	20	8	3

Interruption costs per event

To go a step further in monetizing the resilience benefits, utilities can use the reliability data that they already track to estimate the economic savings from fewer and shorter outages, including the cost of lost productivity, spoilage, and other disruptions. Lawrence Berkeley National Laboratory and Resource Innovations developed the [Interruption Cost Estimate \(ICE\) calculator](#) for utilities, government organizations, and others interested in estimating interruption costs and/or the benefits associated with reliability improvements (ICE Calculator 2025). The ICE calculator uses data from 34 customer interruption cost studies conducted by utilities throughout the United States, serving as a meta-database tool that can generate interruption cost estimates for a specific state and customer base using reliability statistic inputs of System Average Interruption Frequency Index (SAIFI), System Average

¹³ Outage hours will vary if actual building energy data for residential and commercial buildings in a neighborhood is used in resilience analyses. We use PUMA-level energy data from ResStock and ComStock datasets to represent neighborhood energy use. PUMAs and neighborhoods differ; neighborhoods tend to be smaller and more homogenous than PUMAs (for example, buildings may be built around the same decade, with or without access to natural gas). Collecting individual building energy use data to generate the neighborhood energy use can be challenging. In the absence of actual energy use data, ResStock and ComStock datasets remain the most granular tools available.

Interruption Duration Index (SAIDI), and Customer Average Interruption Duration Index (CAIDI) (Clendenning et al. 2024; Sullivan, Schellenberg, and Blundell 2015). Using these datasets, the ICE calculator estimates the cost per outage event per customer (Sullivan, Schellenberg, and Blundell 2015).

When utilizing the ICE calculator, utilities often use the total cost per event to estimate the avoided costs associated with investments (Peter Larsen, staff scientist and leader of the Energy Markets and Policy Department at Berkeley Lab, pers. comm., December 19, 2024). For example, EPB Chattanooga used the ICE calculator to measure the customer benefits of its smart grid investments, funded by DOE, which include 1,200 automated circuit switches and sensors across 171 circuits (EPB Chattanooga and ORNL 2015). These upgrades reduced outage durations by 45% and interruptions by 51%, saving customers \$26.8 million annually in avoided outage costs (EPB Chattanooga and ORNL 2015).

For our study area of southeast Westchester, using publicly available commercial and residential building information and ConEd reliability statistics for 2018, the ICE calculator estimated the cost per unserved kWh as \$18.68 (2023 dollars) or \$20.03 (2025 dollars). In table 4 we use the cost per unserved kWh from the ICE calculator to estimate the total interruption costs in January and August. In our analysis, building energy efficiency measures reduced the number of hours of interruption for customers—that is, SAIDI (the measure of interruption duration) decreased for the study area, resulting in its lower cost per outage event. The reduction in cost per event can be a proxy for the monetary benefit of resilience investment.

Table 4. Estimates of interruption costs per unserved kWh based on ICE calculator outputs

Peak months	Unmet demand 30% electrification + envelope upgrade (kWh)	Unmet demand under 30% electrification (kWh)	Total cost for unmet kWh (2025\$)*
January	42,700	996,400	\$855,281–19,957,892
August	8,000	66,400	\$160,240–1,329,992

*These costs are indicative only. They are estimated based on the value of lost load (VoLL) assumptions in the ICE calculator. Interruption costs decrease when 30% of buildings have both envelope and electrification upgrades, as shown by the lower total cost for unmet kWh.

Utilities can use existing data to value resilience

Utilities currently collect data that can be used to track a number of resilience impacts at the customer and neighborhood levels; we use these data in our valuation approach. Table 5 lists examples of the resilience metrics under three broad categories, along with utility data sources, to show how utilities can use data they already have to estimate the value of resilience and use it in their cost-benefit analyses.

Table 5. Resilience metric categories and examples

Outcomes tracked	Examples
Electric service-related outcomes	Cumulative customer-hours of outages: Florida Power and Light tracks the average customer outage time (Like, Huffman, and Pandey 2024) and could use it to calculate the cumulative customer-hours of outages.

Outcomes tracked	Examples
Time to recovery	Restoration times and other recovery metrics: New York State Public Service Commission Emergency Performance Metrics Scorecard for large-scale outages includes these metrics in its evaluation.
Cost of utility damages and revenues	Indirect costs related to loss of assets and perishables: ConEd compensates small businesses and residential customers for spoilage of food and prescription medications.

Complementing these resilience metrics, our framework offers an approach that utilities can use to track other DOE-defined resilience metrics, the cumulative customer energy demand not served, and reductions in unserved demand due to resilience investments.

Summary of Findings

Localized resilience metrics inform valuation

As resilience becomes a key focus for utilities in the face of extreme weather events and growing electric loads, our framework offers a simplified approach that utilities can use to value localized resilience benefits in their program planning and forecasting efforts. Our approach uses accessible building energy use and utility feeder data to focus on resilience benefits at the neighborhood level. While integrating both customer and grid benefits, our approach recognizes the resilience benefits of energy efficiency at the community scale, acknowledging that the benefits will vary by geographical location and the area's vulnerability to different types of extreme weather. We attribute the value of resilience to three metrics: peak demand reduction, reduced cumulative customer-hours of outage, and lower interruption cost associated with an outage.

Limitations of standard weather data

In utility program planning, whole-building energy use simulation for different energy efficiency measures and the valuation of the resilience benefits from those measures can play an important role and inform decisions about which investments are most cost effective. The simulation results, however, are limited by the assumptions and availability of accurate data. To capture the value of building resilience during an extreme event, a critical input is the weather data. In our analysis, we used actual 2018 weather data that accurately represents the changes to the weather caused by extreme events. Typical TMY weather data average out the temperatures over a period of time and fails to consider extreme anomalies; therefore, it is not the most accurate dataset to assess resilience benefits. The simplification of assumed local weather conditions can produce bias in the results and inaccurate building performance outcomes. To enable utilities to incorporate better predictions of building performance under extreme events into their resilience investment planning, they should use weather data from climate models that project changes in future conditions and accordingly align building model data with that future weather data.

Utilizing high-fidelity data for better predictions

Using high-fidelity building stock data to understand how a large group of buildings uses energy during extreme weather conditions in a geographical area can enable utilities to better assess the potential impacts of their programs; it can also help them prioritize investments that offer the most energy and resilience benefits. To estimate the value of resilience in this report, we use DOE's robust ResStock and

ComStock energy consumption and savings datasets, which comprise hundreds of detailed building energy models and statistically representative building stock information. Using the dataset for the southwest Westchester study area, we found that building energy efficiency investments that combine electrification plus envelope upgrades have the potential to reduce peak summer loads by 8% and lower outage hours by approximately 63%. States and cities can similarly use the ResStock and ComStock dataset for their region or gather actual building energy use data for the study area to identify potential opportunities for energy efficiency improvements, to examine the impact of implementing policies that reduce energy use to enhance neighborhood resilience, and to plan for future energy needs.

Importance of building envelope upgrades

As our analysis demonstrates, electrification without building envelope retrofits will increase the electric load and ultimately stress the grid, escalating the likelihood of outages. We found that during the peak winter month of January, the hours of outages decreased from 50 hours under a 30% rate of electrification to 7 hours under the electrification plus envelope upgrade scenario; this number is likely to increase with higher electrification rates. Given the increased likelihood of outages, maintaining reliability and resilience will require utilities to make systemwide investments to meet the electric demand, which can increase the costs for customers. Utility programs that lower peak electric load through building demand-side interventions can support a more secure, resilient, affordable, and clean energy system.

Applicability of value of resilience to other regions

While we present an example of savings for one region, utilities and decision-makers should undertake detailed analyses to account for the actual utility distribution capacity and building stock data for their own regions to estimate the range of potential resilience benefits. Our analysis illustrates the potential resilience benefits for southeast Westchester from investments in energy efficiency measures. However, every region has unique building stock, utility distribution capacities, and optimal retrofit solutions. The value of resilience will be most comparable to our study for regions with the same climate and with neighborhood buildings that have similar end-use profiles.

Policy gaps and regulatory challenges

At the regulatory level, we lack policies that support the evaluation of building and grid resilience benefits from building energy efficiency measures. In recent years, attention has been given to implementing policies such as winterization regulations or performance credit mechanisms to pay generators that are available to generate electricity during events, but these policies typically focus on improving grid reliability (Skiles, Rhodes, and Webber 2024; Nadel, Amann, and Chen 2023). That is, the solutions have been mostly supply-side interventions to improve the reliability of electricity generation and delivery. We found few examples of utilities like ConEd and FP&L, which are required to gather data on how utility building investments improve resilience and reliability. In addition to the standard reliability measures that most utilities track, data on the resilience benefits of energy efficiency measures is critical to improve program screening and decision-making. To proliferate the approaches, metrics, and the data available for resilience evaluation, utility regulatory commissions can establish requirements for utilities to collect and utilize this data in program cost-benefit analyses.

Conclusion and Recommendations

Many utility energy efficiency programs increase building energy resilience during extreme weather events, with benefits such as enhanced building energy performance, decreased numbers and durations of outages, reduced cost of interruption, and shorter system recovery times. However, these benefits are not included in cost-benefit analyses for energy efficiency programs. Providing the data on the value of resilience benefits to regulators and policymakers can help demonstrate the impact of building energy efficiency investments that provide resilience benefits to communities; that data can also support utilities in their resource decision-making processes to encourage greater investments in DSM programs.

Regulators can standardize methodology to value resilience benefits and make more energy efficiency measures cost effective

Given the increasing frequency and intensity of extreme weather events and the load growth, regulators and program administrators have a key role in accelerating the adoption of resilience valuation methodologies. Identifying the appropriate methodologies to calculate the value of resilience can help ensure that energy efficiency measures are considered alongside energy infrastructure and investment planning efforts to prepare for and prevent the impacts of extreme weather events on the grid and on customers. A few utilities integrate the value of resilience in their program planning and forecasting efforts, but there is a need to standardize the metrics and approaches to building energy resilience valuation.

State regulators and policymakers can direct utilities to conduct benefit-cost analysis of resilience investments when they estimate the simple payback for programs and support the standardization of resilience metrics and evaluation. Standardizing the practices and metrics that assess utility investments in conjunction with addressing information gaps—such as actual weather and residential energy load profile data—will enable utilities to better evaluate and plan for resilience investments. A number of federal, state, and private entities already collect the historical occurrence data for natural hazards, which can be supplemented with actual weather data.

Additionally, regulators should consider developing frameworks and approaches for identifying the beneficiaries of resilience investments and allocating the costs among customer groups. As climate events disproportionately impact vulnerable communities, it is especially important that utilities, regulators, and program administrators center the needs of disadvantaged communities in prioritizing resilience investments.

Utilities can lead reporting on the value of resilience from building investments to support customers and the grid

Our approach provides an aggregated picture of the resilience impacts of investing in building energy efficiency measures at the neighborhood level. Beyond offering energy cost savings, the measures can improve the value of the building and the satisfaction of the tenants. Moving beyond building-level resilience to a neighborhood-level approach could yield more significant results in addressing risk from extreme weather events. Neighborhoods that are collectively more resilient will face fewer disruptions during extreme weather events and will have more-stable energy systems.

Further work in this area can investigate the resilience impacts of different energy efficiency measures. The analyses should evaluate the trade-offs between the costs of energy efficiency measures and the

impact of those investments on the value of resilience, offering a more granular, measure-specific valuation that utilities can incorporate in their program design, planning, and evaluation processes. It is only through analyses that value the energy and resilience impacts of building measures that we can advance and increase the number of energy retrofits that improve the ability of buildings to withstand the threats of extreme weather events and promote the health and safety of communities. Identifying the measures that offer the most customer and grid resilience benefits will allow utilities to prioritize them and restructure their revenue streams and investments based on those priorities. It may also help support investment in systems such as advanced metering infrastructure (AMI) and smart grid upgrades to advance resilience at the neighborhood level.

Federal and state policymakers can utilize empirical data to advance policies and incentives that support behind-the-meter resilience investments

To actualize the resilience benefits that our analysis demonstrates from electrification and energy efficiency measures such as envelope upgrades, establishing policies and incentives to support customer adoption of these measures will be critical. Policies such as tax abatements and incentive programs that subsidize energy efficiency upgrades are essential for supporting electrification upgrades. These mechanisms will be key to facilitating the scale of customer adoption required to move the needle in neighborhood-level resilience. Some measures, such as heat pumps, are more expensive and need more policy support to make them attractive to building owners.

Studies and analysis that value resilience benefits from building energy efficiency measures can help inform regulators on the full set of resilience benefits, enabling them to require utilities to integrate the value of resilience in program screening, capacity planning, and forecasting efforts. In the aftermath of recent extreme weather events, policies have focused on improving the reliability of electricity generation and delivery, overlooking support for demand-side solutions. Residential and commercial building space conditioning loads are weather sensitive and likely to be a larger part of winter peak-demand in the future as electric heating adoption and decarbonization initiatives increase.

As extreme heat or cold events become more frequent and intense, and increase peak electricity demand, improving the energy efficiency of building equipment and appliances can help communities become more resilient by reducing their overall electric load on the local grid, potentially avoiding outages during critical periods. For utilities, regulators, and other stakeholders, understanding the impacts from extreme events is key to protecting energy systems and ensuring our buildings function during and after an event, and support neighborhood resilience. Further studies on resilience benefits from utility programs and their value can enable their integration into program screening and planning efforts and prioritize available options to address resilience gaps, helping proactive investments in solutions to increase the capacity of communities to respond to and withstand the consequences of extreme weather.

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Appendix A: ComStock and ResStock Energy Load Shapes

The data in this report include information from the ComStock and ResStock datasets developed by the National Renewable Energy Laboratory (NREL) with funding from the U.S. Department of Energy.

In its energy modeling processes, ResStock employs both actual meteorological year (AMY) historical weather data and typical meteorological year (TMY3) weather data. ComStock is a model of the U.S. commercial building stock that includes analyses of energy efficiency and electrification measures.

We utilized predefined upgrade packages from the ComStock dataset to model electrification plus envelope enhancements in our analysis. An upgrade package applies one or more end-use savings shapes improvements to a single building model simulation. Given that ComStock is a bottom-up physics-based model,¹⁴ the upgrade package generates results by simulating the interactions between the upgrades instead of aggregating the individual upgrade results. For instance, combining an envelope upgrade with an electrification upgrade would likely yield higher savings than the sum of these upgrades individually. Additionally, if the envelope upgrade significantly reduces the loads, the size of the heating, ventilating, and air-conditioning (HVAC) equipment may be reduced accordingly.

Specifically, from ComStock, our analysis used the following:

- Westchester County SE PUMA TMY3 for baseline electricity consumption
- Westchester County SE PUMA AMY18 to estimate the growth in electricity consumption due to changes in weather conditions compared to TMY18 weather data (which is typically used for building energy analyses)
- Westchester County SE PUMA AMY18 [package 2](#) end-use shapes, which includes three upgrades—LED lighting, air-source heat pump (HP) boilers, and variable speed HP rooftop units (HP-RTU)—that we used to model the electrification scenario. (HP-RTUs are applied to buildings with gas or electric RTUs, while the HP boiler measure is applied to buildings with existing boiler systems; the two types of HPs are not applied together.)
- Westchester County SE PUMA AMY18 envelope [package 1](#), which includes three upgrades: exterior wall insulation, roof insulation upgrade, and a window replacement upgrade to replace a model's windows with thermal and tinting properties specified in the Zero Energy Small/Medium Office Guide for envelope efficiency upgrades. While new windows are expensive and do not have a favorable cost to benefit ratio, they are included in the envelope package, and we were not able to separate their impact in our analysis.
- Westchester County SE PUMA AMY18 package 1 plus package 2 for the combined electrification and efficiency scenario.

ResStock is an analytical tool that simulates the energy consumption of U.S. residential buildings. A key feature of ResStock is its capability to model the existing U.S. building stock while incorporating various scenarios, including different energy efficiency measures. In the end-use savings shapes datasets, this feature is used with various envelope, equipment, and electrification measures that are bundled together into measure packages. For Westchester County southeast PUMA, the ResStock load profile

¹⁴ Parker, Andrew, et al. 2023. *ComStock Reference Documentation*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-83819. <https://www.nrel.gov/docs/fy23osti/83819.pdf>.

(baseline) is based on 174 building energy models. We selected predefined measure packages in ResStock for modeling the electrification + envelope upgrades.

The particular files we use from ResStock are as follows:

- Westchester County SE PUMA TMY3 (baseline)
- Westchester County SE PUMA AMY18 to estimate the growth in electricity consumption due to changes in weather conditions compared to TMY18 weather data, which is typically used for building energy analyses
- NY AMY2018 whole-home electrification package, which includes high-efficiency ducted variable speed HPs with electric backup SEER 24, heating seasonal performance factor (HSPF) rating of 13 for dwelling units with ducts; ductless variable speed mini-split SEER 29.3, 14 HSPF for units without ducts; HP water heaters for all dwelling units; ventless HP dryers; electric ovens; and induction stoves.
- NY AMY2018 basic envelope upgrade, which includes attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation; general air sealing with 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50; duct sealing in dwelling units with leakier and/or less insulated ducts located in unconditioned space; and drill-and-fill wall insulation in dwelling units with uninsulated wood stud walls.
- NY AMY2018 whole-home electrification and basic envelope upgrade, which includes high-efficiency HPs, HP water heaters, ventless HP dryers, induction ranges, attic floor insulation, air leakage reduction, duct sealing, and wall insulation.

The latter three files are at the state level because end-use savings shapes are not available at the PUMA level. For these scenarios, we ascribed savings at the PUMA level using the proportion of population in the state.