THE PORT PREPARDNESS PLAN

CITY OF CAMBRIDGE, MASSACHUSETTS

Appendix 2
Energy Resilience for The Port
Technical Memo

20181727.001 May 22, 2019

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1 Executive Summary

This Energy Resilience Technical Memorandum ("Memo") documents the research and analysis performed for The Port Preparedness Plan, which is part of the citywide Cambridge Climate Change Preparedness and Resilience (CCPR) Plan. This Memo provides the context and recommendations for actions to increase energy resilience in The Port area of Cambridge. These recommendations specifically address building-scale energy resilience for new and existing "triple-decker," multifamily, and commercial buildings for two "Model Resilient Blocks" within The Port, and neighborhood-scale energy resilience for The Port area as a whole.

1.1 The Problem

Previous research developed for the City of Cambridge shows a clear need for climate action, including climate resilience and adaptation.[1] Although the City has performed extensive planning for climate mitigation, including the Cambridge Net Zero Action Plan and Cambridge Climate Action Plan, it must also prioritize adaptation and resilience to ensure the long-term health, safety, and welfare of its constituents. Unattended, worsening effects of climate change will increase the risk of damage to buildings, infrastructure, and economic activity, and potentially endanger the residents and businesses of Cambridge.

1.2 Guiding Questions

Planning for climate change resilience is a challenging endeavor, as it involves a wide range of intersecting topic areas and requires a long-term outlook; although immediate action may be needed to prevent future risks, some of the most visible effects of climate change may not manifest for many years. A series of guiding questions were established to ensure that the recommendations included in this Memo effectively address energy resilience while considering implications for other relevant topic areas such as public health and equity:

1. What are the most effective solutions, in terms of the benefits created and likelihood of successful implementation, for improving the energy resilience of buildings and communities?
2. How can the City best support and encourage the implementation of energy resilience actions, and what are the current challenges to implementation?
3. How can the City pursue energy resilience in a way that maximizes the creation of additional benefits such as reduced energy consumption and greenhouse gas (GHG) emissions?
4. How can the City pursue energy resilience actions in a way that protects vulnerable residents from displacement and ensures that those residents share in the resulting benefits?

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[1] City of Cambridge, Climate Change Vulnerability Assessment (CCVA) Report. https://www.cambridgema.gov/CDD/Projects/Climate/climatechangeresilianceandadaptation

1.3 Approach and Goals

The CCPR Plan, when released, will provide recommendations for resilience that are applicable throughout the City of Cambridge. As part of the CCPR process, two focus areas were identified—Alewife and The Port, the latter of which is the subject of this Memo—to better study and address the physical and social risks created by climate change. Although use of focus areas facilitates a more detailed study of existing conditions and associated opportunities and challenges, many of the issues described in this Memo are not limited to The Port.

The recommended actions for energy resilience provided by this Memo were evaluated using indicators that are applicable citywide, including the relative cost and difficulty of implementation, estimated timeline for adoption, and potential reductions in energy consumption and GHG emissions. The potential climate change mitigation benefits of energy resilience were specifically addressed to demonstrate the value of a coordinated approach, combining resilience with energy efficiency to create additional incentives and improve the feasibility of certain actions.

However, although there are many policies and programs at both the State and City level to support energy efficiency and clean energy adoption, it is now estimated that the current pace of GHG emissions reductions will not be sufficient to mitigate projected climate change impacts.[2] Thus, it is imperative that the City of Cambridge take action to address climate change risks.

Ultimately, the goal of The Port Preparedness Plan, this Memo, and the CCPR Plan overall, is to identify strategies for increasing energy resilience that are actionable, progressive, equitable, and effective.

1.4 Key Findings

A major issue addressed throughout this memo is the effect of extreme heat on infrastructure, buildings, and the population. The combination of heat waves and power outages, which often result from such conditions, create dangerous conditions for building occupants, as the systems that maintain safe thermal conditions and critical life support functions may not function. This risk is not limited to extreme heat—lack of power during cold weather conditions are equally dangerous. Extended power outages that last multiple days increase this risk, as indoor temperatures may quickly rise or plummet in buildings that were not designed for high thermal performance.

It is expected that climate change will contribute to an increase in extreme heat events, precipitation-based flooding, and winter storms (i.e., nor'easters) affecting Cambridge and the surrounding region. In terms of energy, flooding and storms can damage infrastructure and building systems, whereas extreme heat can reduce the capacity of electricity generation and distribution. Although heating currently represents a majority of thermal energy loads (i.e., energy consumed to provide heating and cooling) in

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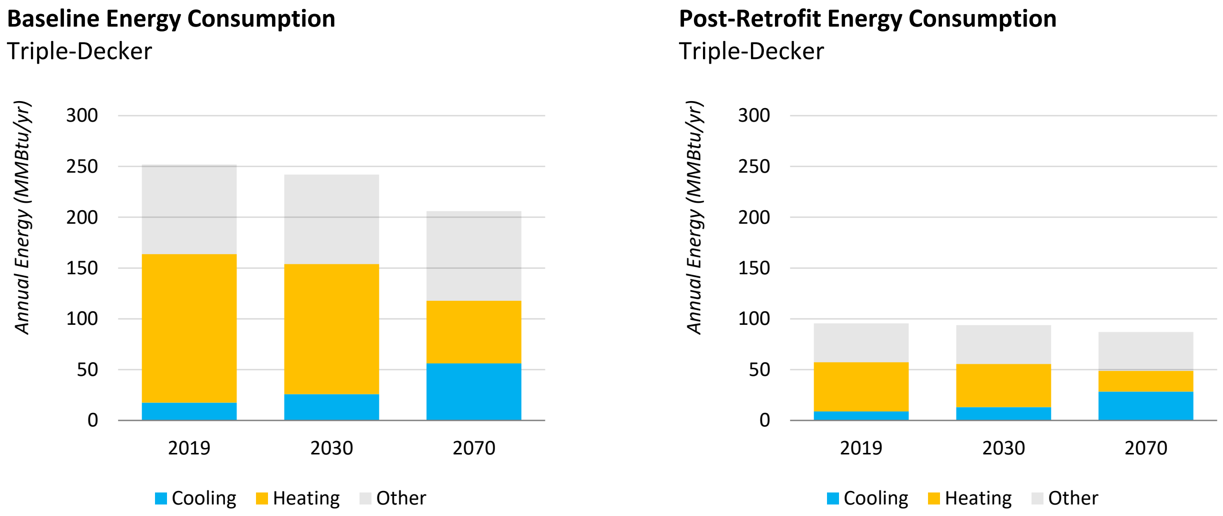
[2] U.S. Global Change Research Program, Fourth National Climate Assessment, November 2018. https://www.globalchange.gov/nca4

Cambridge, by the year 2070 rising temperatures may result in equal if not higher cooling loads. Moreover, the use of air conditioning will increase as building occupants attempt to contend with higher temperatures.

Figure 1 and Figure 2 show the projected increase in energy consumption for space heating and cooling in 2030 and 2070 for an existing triple-decker and commercial building, respectively, representing typical conditions (i.e., existing building systems and construction) and post-retrofit conditions.[3] Under both conditions, the projected increase in cooling loads and decrease in heating loads would result in a net reduction in overall residential energy consumption, as space heating comprises a majority of existing residential loads. The opposite is true for commercial buildings, for which cooling loads are typically a significant portion of overall energy consumption.


Baseline Energy Consumption
Triple-Decker

Post-Retrofit Energy Consumption
Triple-Decker

Figure 1 – Projected baseline and post-retrofit energy consumption for a typical triple-decker[4]

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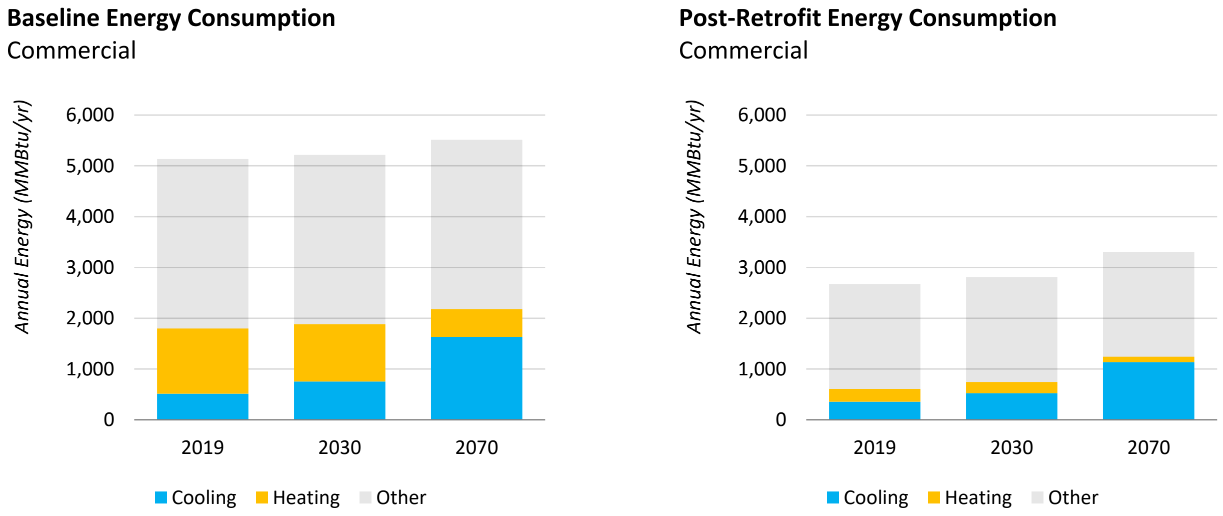
[3] Post-retrofit conditions assume implementation of the energy resiliency retrofits described in Sections 4.2.1 and 4.2.2 of this Memo.

[4] The “other” category represents energy consumption that is not directly related to space heating and cooling, including domestic hot water (DHW), plug loads, lighting loads, and other miscellaneous loads.



Baseline Energy Consumption
Commercial

Post-Retrofit Energy Consumption
Commercial

Figure 2 – Projected baseline and post-retrofit energy consumption for a typical commercial building

The increase in energy consumption resulting from higher cooling loads and air conditioning use will exacerbate the utility-scale capacity issues created by extreme heat, which could increase the frequency and duration of outages. This poses a significant public health risk, especially for vulnerable populations without the means to relocate, as buildings may become dangerously hot during prolonged outages. The ability to "shelter in place" during outages is not limited to extreme heat—buildings can become dangerously cold during winter outages caused by intense storms or flooding.

A majority, if not all of the energy resilience actions recommended for existing buildings entail retrofits to building envelopes or mechanical systems, which are also often the focus of energy efficiency upgrades. This creates an opportunity to combine energy efficiency upgrades with those for energy resilience, improving the economic feasibility of such actions and achieving greater levels of adoption. The challenges associated with implementing energy resilience actions in existing buildings are primarily the result of the difficulties associated with retrofitting the city's older building stock, split incentives between building owners and tenants (e.g. owner investments in building upgrades benefit tenants by lowering the cost of their utility bills), and the already-high cost of housing.

Energy resilience actions for existing buildings are provided in Table 1 below, which includes estimated reductions in annual energy consumption and GHG emissions, compared to baseline values, for a single building. See Section 4 of this Memo for a more detailed description of energy resilience strategies for existing buildings and associated energy and GHG emissions benefits.

Table 1 – Energy resilience strategies for existing buildings and associated reductions in energy consumption and GHG emissions

	Strategy	Action	Energy/GHG Reduction[5]
B3	**Flood Protection for Existing Buildings**	Elevate or protect vulnerable utilities	-
B	**NEW**	Replace vulnerable equipment with high-efficiency electric heating, cooling, and DHW systems	23-44% reduction in energy consumption; 15-38% reduction in GHG emissions
B4[6]	**Heat Protection for Existing Buildings**	Install solar power and energy storage systems	8-12% reduction in energy consumption; 12-14% reduction in GHG emissions
		Upgrade windows and insulation, and air-seal windows and doors	11-12% reduction in energy consumption; 2-10% reduction in GHG emissions
		Upgrade roofing with reflective and/or light-colored materials	0-1% reduction in energy consumption; 0-1% reduction in GHG emissions

Note: Strategies are ordered as presented in the CCPR Handbook and the order of presentation is not indicative of their relative importance.

Similar opportunities exist for new buildings to combine measures for energy resilience and energy efficiency. Although Cambridge has adopted the Massachusetts State Stretch Energy Code, and a wealth of incentives are available for energy efficient construction, new buildings may still be designed without considerations with energy resilience. Moreover, the aforementioned regulations and incentives may not address building performance to the extent necessary for the City to meet its sustainability and climate goals.

In term of neighborhood-scale energy resiliency, microgrids and community energy systems are both viable options for The Port. Microgrids can provide both energy resilience and improved energy efficiency, in addition to numerous other co-benefits. Traditionally, microgrids are defined as groups of interconnected loads (i.e., buildings or other energy consumers) and distributed energy resources (e.g., on-site solar panels or natural gas generators) that can be controlled as a single entity, much like a large

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[5] All values estimated. Energy and GHG reductions calculated based on timeframe of implementation (e.g., the calculation of energy savings attributed to high-efficiency mechanical systems assumes that envelope upgrades have already been performed). See Section 8.1 of this Memo for methodology and assumptions.

[6] Resilience actions may be eligible for City or State assistance, including rebates and financing.

building, and are able to disconnect from the central electricity grid during an outage while continuing to deliver power.

Because traditional microgrids typically require the construction of new infrastructure and generation sources, and may encounter a lengthy approvals process, they are often costly to implement. A short-term, complimentary solution to this may be the implementation of “community energy” systems. Similar to microgrids, community energy systems are comprised of groups of loads and distributed energy resources that function as a single entity. However, these resources are managed virtually, and are not connected via physical infrastructure.

Community energy systems can serve as the first step towards traditional microgrid implementation by creating distributed energy resource and establishing a managing entity. This can help reduce the cost of microgrid construction and provide more time for any ownership, financing, and regulatory challenges to be resolved. Additionally, community energy systems can reduce stress on local distribution systems by better managing peak loads. However, unlike traditional microgrids, community energy systems cannot maintain power during outages for buildings where distributed energy systems are not installed.

2 Project Context

This Energy Resilience Technical Memorandum (“Memo”) documents the research and analysis performed for The Port Preparedness Plan, which is part of the citywide Cambridge Climate Change Preparedness and Resilience (CCPR) Plan. The primary objective of the CCPR effort is to identify strategies for preparing and adapting to the risks identified in the previous Climate Change Vulnerability Assessment (CCVA).[7] As part of the CCPR process, two focus areas were identified to better study and address the physical and social risks created by climate change: Alewife and the Port.

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[7] City of Cambridge, Climate Change Vulnerability Assessment (CCVA) Report. https://www.cambridgema.gov/CDD/Projects/Climate/climatechangeresilianceandadaptation

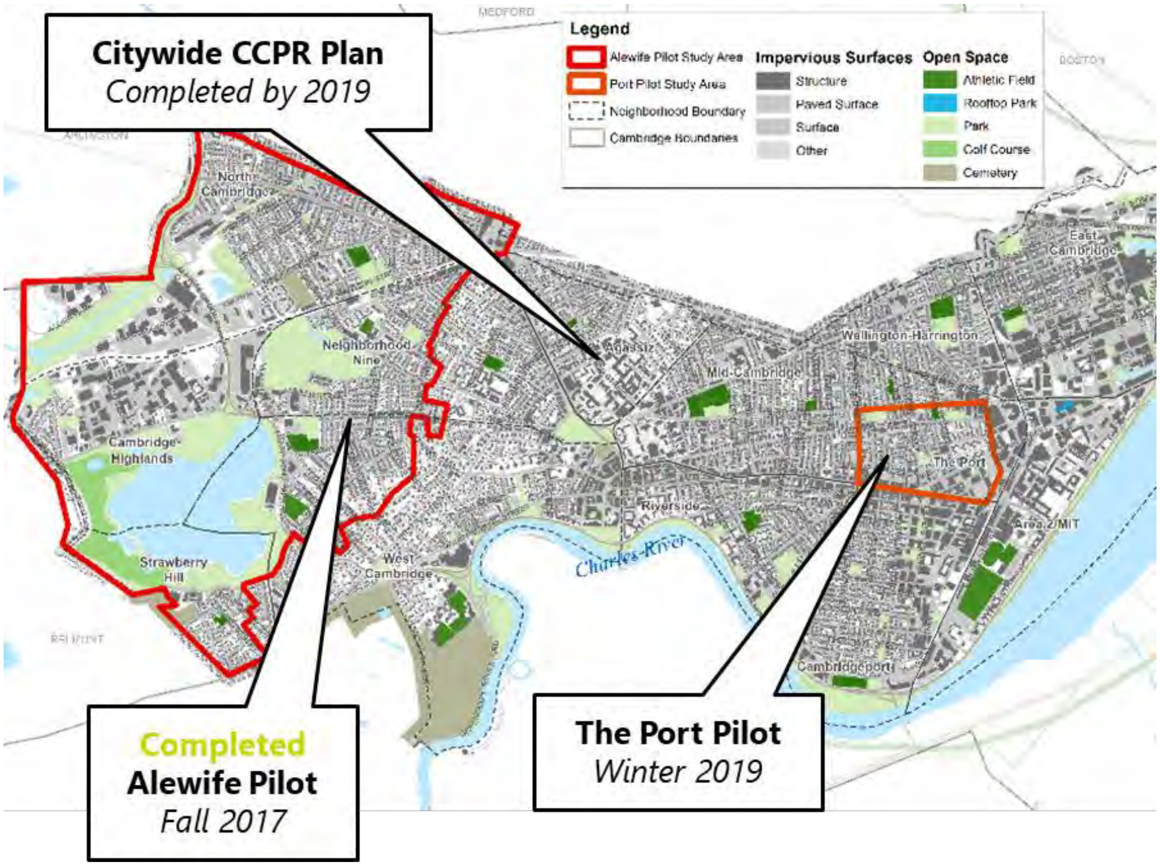

Figure 3 – Scope and timing of Cambridge Climate Change Preparedness and Resilience Plan components

The Alewife Plan was completed in the fall of 2017. It provided a series of strategies and actions to enhance resilience in the area, which were organized into the following four categories:

A. **A Prepared Community:** Strategies to strengthen community, social, and economic resilience
B. **Adapted Buildings:** Strategies to protect buildings against projected climate change impacts
C. **Resilient Infrastructure:** Strategies to ensure continued service or a speedy recovery from community-wide infrastructure systems
D. **Resilient Ecosystems**: Strategies using trees and other vegetation to mitigate the Urban Heat-Island (UHI) effect to protect vulnerable populations from the negative health impacts of extreme heat, improve water quality, and reduce flooding impacts from smaller storm events

These categories were retained for The Port Preparedness Plan, and many of the energy resilience actions recommended for Alewife were expanded or modified based on the additional research and analysis performed specifically for the Port. This Memo focuses on categories B and C, presenting strategies for energy resilience at the building and infrastructure scale, respectively.

2.1 Related Plans and Initiatives

As previously stated, the City's rigorous climate change vulnerability assessment, documented in the CCVA Report, establishes the technical foundation for the CCPR planning process.[8] The CCVA Report focused on risks created by increasing temperatures, precipitation, and sea level. Because Alewife was identified as one of the neighborhoods most vulnerable to severe flooding, it became the first focus area for the CCPR Plan. The following plans and initiatives were reviewed as part of the CCPR planning process and, to the extent possible, the strategies provided in this Memo are intended to align with and support their goals.

The Cambridge Net Zero Action Plan (NZAP), introduced in 2015, established a framework for the city to achieve net zero GHG emissions, with a focus on building emissions.[9] The NZAP establishes policy targets for achieving net zero GHG emissions for all new buildings by 2030, and all existing buildings by 2050. Policy actions for new buildings will begin in 2020, and focus on municipal buildings; actions for non-municipal new and existing buildings will be implemented between 2022 and 2030. Policies and programs for existing buildings were developed at the adoption of the NZAP and will continue to be expanded. Additionally, the NZAP includes strategies for increasing the supply of low-carbon energy to accelerate the adoption of renewable energy sources.

The Cambridge Climate Action Plan (CAP) was updated in 2018 to reflect the City's 2012 Community-wide GHG inventory; the City's first Climate Protection Action Plan was released in 2002.[10] The CAP describes how the City will achieve its commitment to carbon neutrality by 2050, and contains strategies—some of which are referenced from the NZAP and other, similar initiatives—to reduce GHG emissions across buildings, transportation, and waste sectors. Although the current set of strategies do not fully achieve the City's aforementioned carbon neutrality goal, the CAP will continue to evolve as new strategies for reducing GHG emissions are developed.

Envision Cambridge is the City's comprehensive plan, which incorporates past and ongoing planning initiatives and will result in actionable recommendations for a more livable, sustainable, and equitable Cambridge.[11] Similar to the CCPR Plan, Envision Cambridge performed a specific study of Alewife comprised of focus groups, visioning workshops, and draft design guidelines.

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[8] Ibid.

[9] City of Cambridge, Net Zero Action Plan. https://www.cambridgema.gov/CDD/Projects/Climate/netzerotaskforce

[10] City of Cambridge, Climate Action Plan. https://www.cambridgema.gov/CDD/climateandenergy/climatechangeplanning/climateactionplan

[11] Envision Cambridge. http://envision.cambridgema.gov/

2.2 Relevant Policies and Programs

A number of policies and programs at both the City and State level are available to support energy resilience, as a majority of the actions recommended in this Memo also produce energy efficiency and GHG emissions reduction benefits.

2.2.1 City of Cambridge

In 2014, the City of Cambridge enacted the Building Energy Use Disclosure Ordinance (BEUDO), a key component of the City's effort to reduce GHG emissions. [12] Buildings account for 80 percent of GHG emissions citywide, and the ordinance is intended to address this by requiring large buildings to track and report their energy use on an annual basis. This data may then be used to create value for higher-performing properties, and help the City develop policies for building energy reduction. Currently, the ordinance is only applicable to non-residential buildings greater than or equal to 25,000 square feet in area, residential buildings with 50 or more units, and municipal buildings greater than or equal to 10,000 square feet in area.

The Cambridge Energy Alliance (CEA) is a City of Cambridge program that promotes energy efficiency and solar energy.[13] To support its goal of helping residents, businesses, and institutions save money while also reducing GHG emissions, the CEA promotes the Mass Save incentives for energy upgrades and connects property owners to sources of financing for energy efficiency improvements and solar energy projects. This includes Sunny Cambridge, a citywide initiative that identifies local solar installers and helps residents request and compare quotes.[14]

The CEA launched the Multi-Family Energy Pilot in 2017 to help multifamily condo and apartment buildings implement solar energy and energy efficiency upgrades. This pilot provides residents with a Retrofit Advisor to facilitate energy and solar assessments, identify qualified contractors, and determine the most appropriate financing options for their project. Since the Pilot was launched, more than 1,300 households have participated.[15]

2.2.2 Commonwealth of Massachusetts

Mass Save is a statewide, gas and electric utility-run program that offers services and incentives for a wide range of energy upgrades.[16] This includes energy efficiency rebates and incentives for building

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[12] City of Cambridge, Building Energy Use Disclosure Ordinance. https://www.cambridgema.gov/CDD/zoninganddevelopment/sustainablebldgs/buildingenergydisclosureordinance

[13] Cambridge Energy Alliance. https://cambridgeenergyalliance.org/

[14] EnergySage, Sunny Cambridge. https://www.energysage.com/sunnycambridge/

[15] Cambridge Energy Alliance, The Cambridge Multi-Family Energy Pilot. http://cambridgeenergyalliance.org/current-efficiency-promotions

[16] Mass Save. https://www.masssave.com/en/

owners and tenants, which cover heating and cooling system upgrades, building envelope improvements (e.g., insulation, air sealing), and new construction and major renovations. Mass Save also administers the HEET Loan program, which provides qualified landlords and condo owners with a zero-interest loan of up to $25,000 for certain energy efficiency improvements, including heat pump installations.[17]

The Massachusetts Clean Energy Center (MassCEC) is a state economic development agency dedicated to accelerating the growth of clean energy in Massachusetts.[18] MassCEC offers rebates, vouchers, and loans for the installation of renewable clean energy technologies in residential buildings, and provides rebates and technical assistance for businesses interested in increasing their clean energy output. MassCEC also works with emerging industries within the clean energy sector, including energy storage and microgrids. In early 2018, the MassCEC announced $1.05 million in funding for 14 microgrid feasibility studies as part of its Community Microgrids Program.[19]

The Solar Massachusetts Renewable Target (SMART) program, created by the Massachusetts Department of Energy Resources (MassDOER), is a long-term incentive program to support solar energy projects.[20] The program offers tariff-based incentives paid by the electricity utility company directly to the solar energy system owners, who may be third-party operators. MassDOER also incentivizes the installation of technologies such as air source heat pumps (ASHPs) by provides Alternative Energy Certificates (AECs), which accrue based on output and can be sold through the Alternative Energy Portfolio Standard (APS) market.[21] MassDOER and MassCEC have also jointly launched the Mass Solar Loan Program for residents interested in directly owning solar energy systems. This program provides low-interest, fixed-rate loans to both homeowners and small participants in community shared solar associations.[22]

2.3 Climate Change Impacts

The City of Cambridge is most vulnerable to climate change risks associated with extreme heat, more frequent and severe storms, and precipitation-based flooding. These risks and associated vulnerabilities are described in the context of energy resilience in the following subsections.

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[17] Mass Save, Mass Save® HEAT Loan. https://www.masssave.com/en/saving/residential-rebates/heat-loan-program/

[18] Massachusetts Clean Energy Center. https://www.masscec.com/

[19] Massachusetts Clean Energy Center, Community Microgrids Program. https://www.masscec.com/community-microgrids-program

[20] Commonwealth of Massachusetts, Solar Massachusetts Renewable Target (SMART). https://www.mass.gov/solar-massachusetts-renewable-target-smart

[21] Commonwealth of Massachusetts, Alternative Energy Portfolio Standard. https://www.mass.gov/alternative-energy-portfolio-standard

[22] Commonwealth of Massachusetts, Massachusetts Solar Loan Program. https://www.mass.gov/service-details/massachusetts-solar-loan-program

2.3.1 Extreme Heat

Both annual temperatures and the frequency and duration of extreme heat events are expected to increase over the next 50 years and beyond. This is particularly challenging for Cambridge, as its buildings and infrastructure were originally designed for a cooler climate.[23] In terms of energy supply, extreme heat can negatively affect the performance of electricity infrastructure and assets. Heat waves can reduce the capacity of power lines, transformers, and generators, potentially resulting in rolling blackouts or outages.

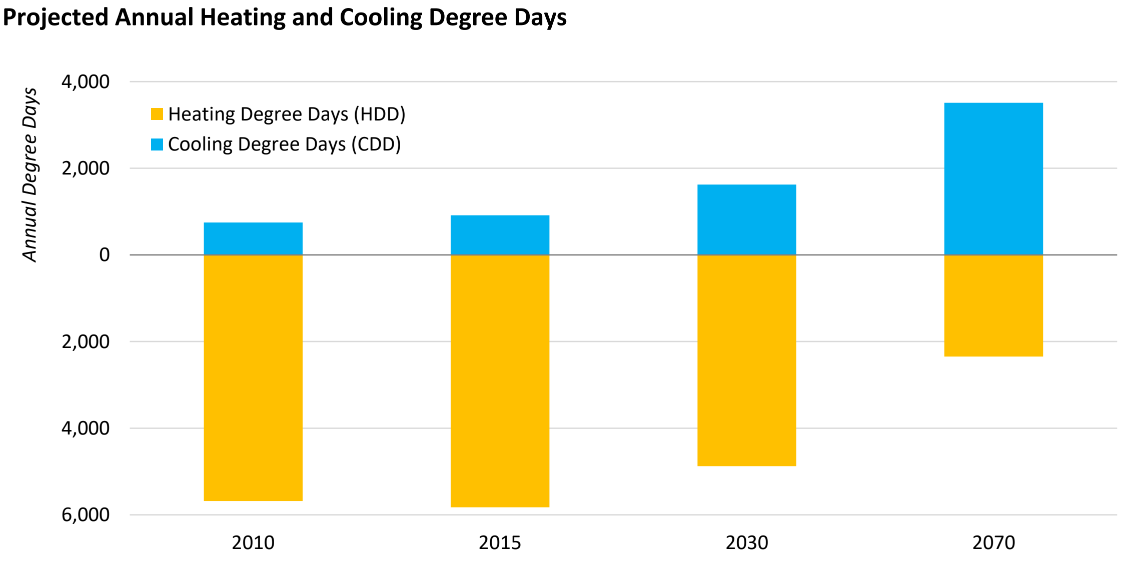

Figure 4 – Historic and projected annual heating and cooling degree days[24]

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[23] City of Cambridge, Climate Change Vulnerability Assessment Report – Part 1, Climate Projections & Scenario Development, November 2015. https://www.cambridgema.gov/CDD/Projects/Climate/~/media/15687E2123FE4AD8A4DA5BB1B1A06D10.ashx

[24] Petri, Y. and Caldeira, K. Impacts of global warming on residential heating and cooling degree-days in the United States, 2015. BuroHappold analysis.

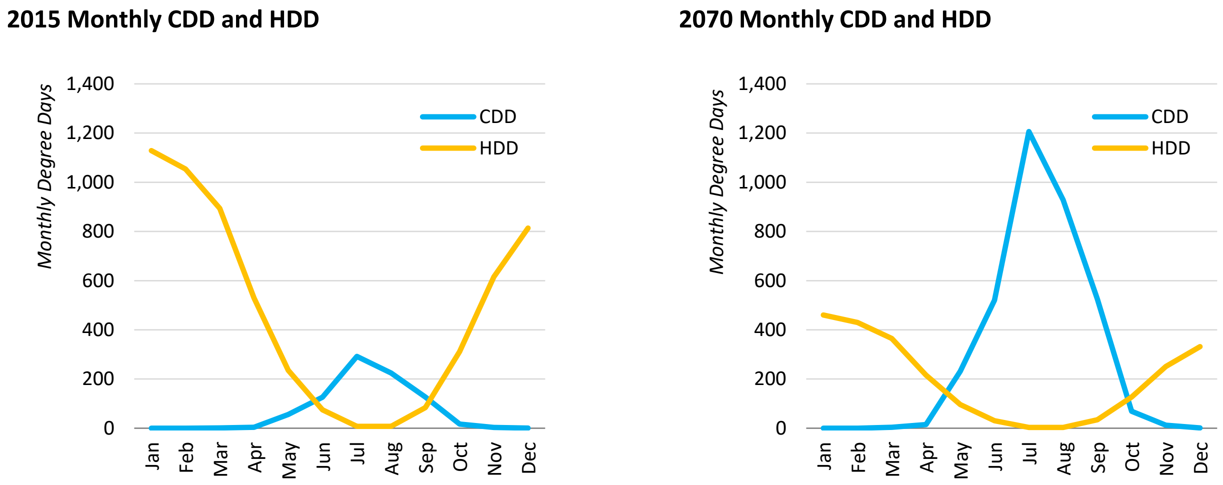
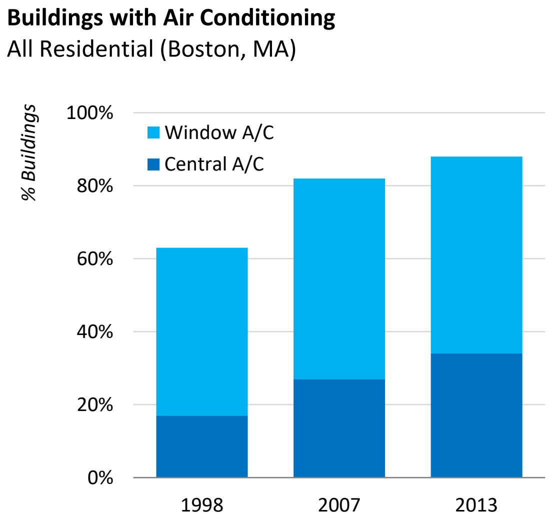


Figure 5 – Monthly heating and cooling degree days for 2015 and 2070[25]

This condition is likely to be exacerbated by an increase in building air-conditioning loads in response to the higher temperatures. Figure 4 and Figure 5 show the change in heating degree days (HDD) and cooling degree days (CDD) between now and 2070. HDD and CDD are measurements designed to quantify the energy needed to heat or cool a building, and represent the number of degrees that an average daily temperature deviates from a given base temperature where heating or cooling would not be needed. These charts show that by 2030 building cooling loads could double, and by 2070 cooling loads could be twice that of heating loads.



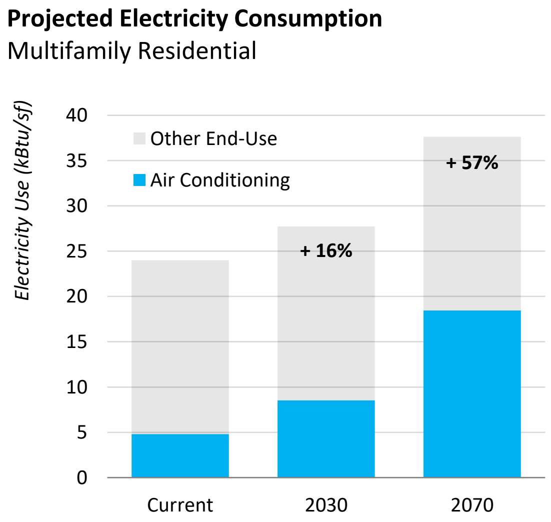


Figure 6 (Left) – Residential building air conditioning use in Boston, MA between 1998 and 2013 [26]

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[25] 2015 CDD and HDD from DegreeDays.net; 2070 CDD and HDD from BuroHappold analysis

[26] US Census, American Housing Survey (AHS).

Figure 7 (Right) – Current and projected electricity consumption for a multifamily residential building in Cambridge [27]

As shown in Figure 6 and Figure 7, buildings in the Cambridge and Boston area are increasingly installing central air conditioning systems, or opting to use window air conditioners to provide cooling. As average temperatures continue to increase, there will not only be more air conditioner use citywide, the electricity consumed to provide cooling on a building-by-building basis will also increase.

Power outages during periods of extreme heat create additional economic and public health issues, as the systems that maintain safe thermal conditions and critical life support functions may not function, and indoor environmental conditions may progress from uncomfortable to unsafe. This risk is not limited to extreme heat—lack of power during cold weather conditions are equally dangerous. Extended power outages that last multiple days increase this risk, as indoor temperatures may quickly rise or plummet in buildings that were not designed for high thermal performance.

Previous studies have shown that, during a summer power outage, temperatures within a single-family wood-frame house—a similar construction type to Cambridge's double/triple-deckers—would exceed 90° F within three days. During a winter power outage, temperatures within that same building could drop below 50° F within 24 hours.[28] These risks are not limited to Cambridge, and as the risks of climate change become more well-defined, there has been growing interest in strategies to keep building occupants safe and provide some measure of functionality during prolonged outages.

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[27] BuroHappold analysis. EIA 2009 RECS Survey Data, Table CE4.7 Household Site End-Use Consumption by Fuel in the Northeast Region, Averages, 2009.

[28] Urban Green Council, New York Chapter of the U.S. Green Building Council, "Baby Its Cold Inside," February 2014. https://www.urbangreencouncil.org/babyitscoldinside

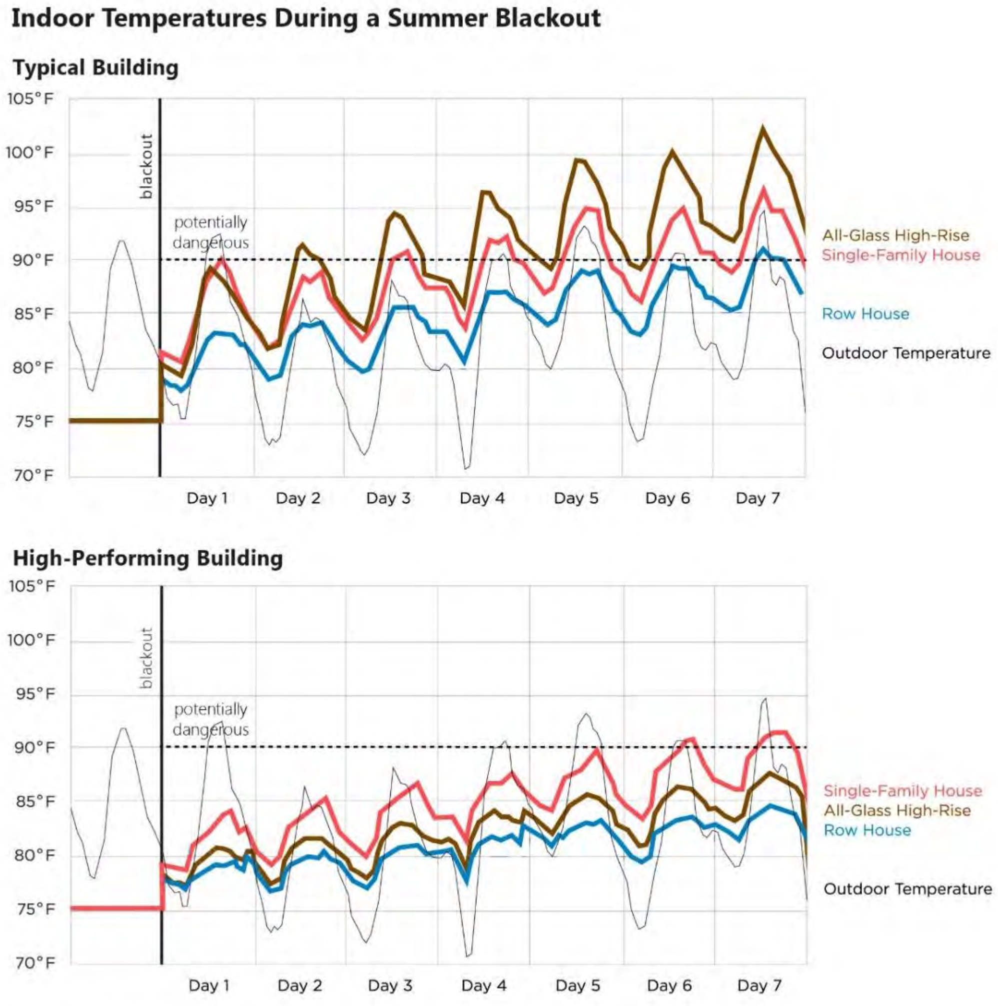

Figure 8 – Change in indoor temperatures during a summer power outage.[29]

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[29] Ibid.

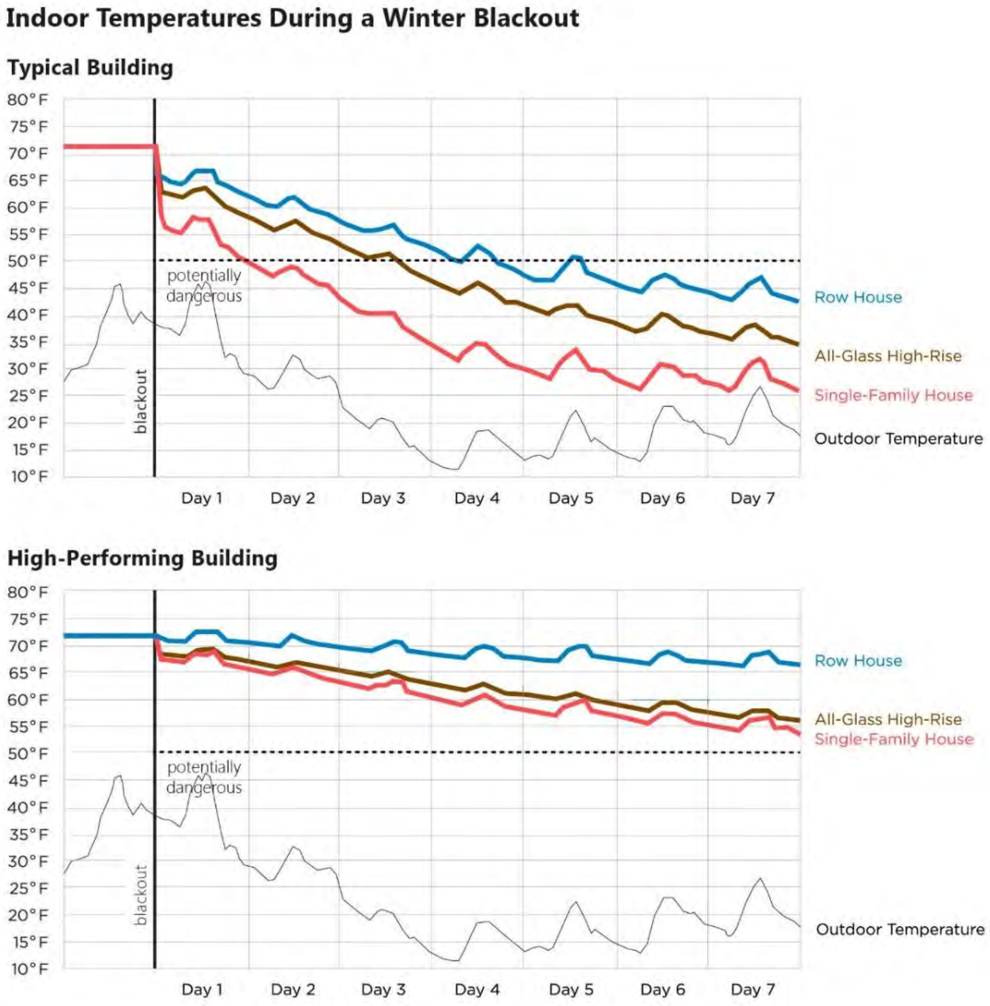

Figure 9 – Change in indoor temperatures during a winter power outage.[30]

The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) rating system recently incorporated new resiliency pilot credits to address "passive survivability" (i.e., the ability of a building to passively maintain thermally safe conditions during a power outage) and backup power during disruptions, which are worth one LEED point each. Passive survivability can be achieved through measures such as highly insulated building envelopes and natural ventilation, and LEED applicants may either pursue Passive House certification as a means for compliance or demonstrate through modeling that thermally safe conditions would be maintained during a power outage lasting four days during either peak summertime and wintertime conditions or a typical meteorological year. [31]

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[30] Ibid.

[31] U.S. Green Building Council, LEED v4, LEED BD+C: New Construction, Passive Survivability and Back-up Power During Disruptions. https://www.usgbc.org/credits/passivesurvivability

The LEED credit for backup power requires the provision of electricity for three or more specified power demands, including electrical components of fuel-based heating systems, cooling equipment, pumps for potable water distribution, and egress lighting. The required duration of backup power is based on facility type, but defers to local building regulations where more stringent (Table 2).[32]

Table 2 – LEED v4 requirements for back-up power duration

Facility Category	**Facility Type**	**Required Duration**
Baseline Facilities	Residential buildings, lodging, hospitals, nursing homes, emergency shelters and facilities, fire stations, 911 call centers, police stations and similar.	Four (4) consecutive days, 24 hours per day.
Fundamental Community Service Organizations	Pharmacies, convenience stores, grocery stores and facilities with significant food stocks.	Four (4) consecutive days, eight (8) hours each day during daylight hours for general operations. Refrigeration and freezers, four (4) consecutive days, 24 hours per day. ATMs powered during regular business hours.
	Gas Stations.	Four (4) consecutive days, 12-hour each day (or until fuel stocks are exhausted), primarily during daylight hours. Backup power or built-in hand pumps for fuel distribution.
Solar and Wind Electric Back-up Power Systems with Energy Storage		One-half (1/2) of the duration of backup power as identified as described above (excluding elevators) for solar or wind electric systems and battery storage. Gas stations must have built-in hand pumps for fuel distribution.

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[32] Ibid.

2.3.2 Nor’easters

Nor’easters are powerful winter storms that are typically accompanied by heavy rain or snow, and can cause flooding, hurricane-force winds, or blizzard conditions. It is likely that climate change will increase the frequency and intensity of these storms in the future, creating a greater risk of damage in Cambridge. Ice, strong winds, and flooding may reduce mobility during and after a storm, forcing residents and workers to shelter in place, preventing fuel oil deliveries from reaching certain customers, and increasing the time needed to repair damaged infrastructure and restore service.[33]

2.3.3 Precipitation-Based Flooding

Precipitation-based flooding is likely to increase as precipitation events, including the previously mentioned Nor’easters, become more frequent and intense.[34] Flooding may damage electricity distribution infrastructure directly through contact between energized equipment (e.g., underground power lines, transformers) and floodwaters. Soil erosion caused by flooding may also undermine the foundations of utility poles, causing them to collapse, or the roots of adjacent trees, which may fall on overhead power lines.

At the building scale, flooding may damage mechanical and electrical equipment located beneath the flood elevation (e.g., in basements). The hydrostatic pressure of floodwaters may also damage building walls and foundations, potentially compromising the entire structure.

3 The Port Pilot

The Port was selected as a focus area for the CCPR Plan because it is representative of typical development patterns found throughout Cambridge, and, similar to Alewife, is vulnerable to both current and future risks posed by flooding and extreme heat. Although the exact boundaries of The Port may vary between sources, for the purposes of this Memo, The Port is bounded by Broadway and Massachusetts Avenue to the north and south, and Vassar Street, Galileo Galilei Way, and Prospect Street to the east and west (Figure 10).

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[33] City of Cambridge, Climate Change Vulnerability Assessment Report – Part 1, Climate Projections & Scenario Development, November 2015. https://www.cambridgema.gov/CDD/Projects/Climate/~/media/15687E2123FE4AD8A4DA5BB1B1A06D10.ashx

[34] Ibid.

Figure 10 – Boundaries of The Port (credit: Kleinfelder)

A majority of buildings within The Port are detached residential structures, although there are a significant number of City-owned multifamily residential buildings that are managed by the Cambridge Housing Authority (CHA). A number of smaller retail businesses are located along key commercial corridors (e.g., Broadway, Massachusetts Avenue), and large commercial office and laboratory facilities located east of Portland Street and South of Main Street. In addition to CHA, the Massachusetts Institute of Technology, Novartis, and Alexandria are also major property owners within The Port.

3.1 Resilient Urban Blocks

Within The Port, two sites to test as Resilient Urban Blocks were identified that represent building and land use characteristics that are typical to the neighborhood and city as a whole (Figure 11).

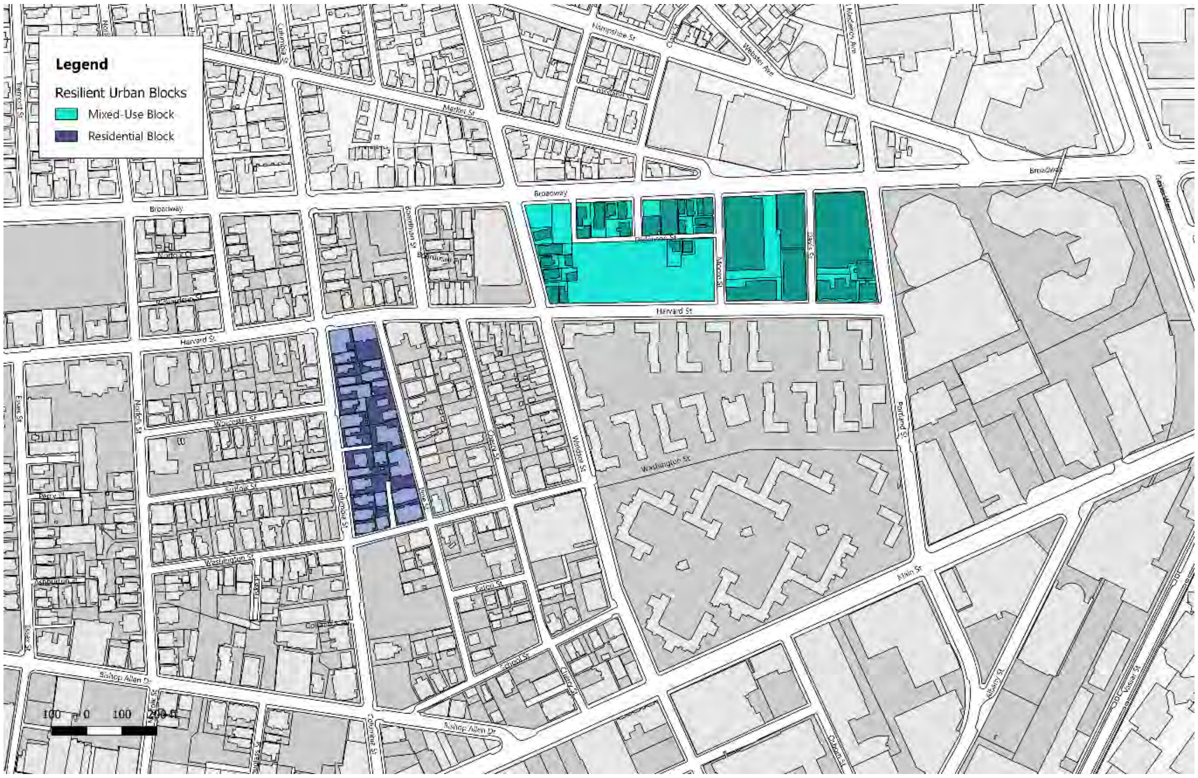

Figure 11 – Mixed-use (green) and residential (purple) Resilient Urban Blocks

The Mixed-Use Block is composed of a commercial office, retail, and residential properties at various scales, and is bounded by a combination of primary and secondary streets. The Residential Block is composed of residential properties ranging in size from one to six dwelling units. Existing conditions for both Blocks are summarized in Table 3.[35]

Table 3 – Summary of existing building characteristics for Resilient Urban Blocks in The Port

Parameter	Mixed-Use Block	Residential Block
Number of Buildings	35	26
Total Floor Area (sf)	381,200	88,400
Residential Units	114	75
Commercial Area (sf)	255,400	4,800
Pct. Commercial Area	67%	5%

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[35] Building characteristics were derived from the City of Cambridge FY2019 Assessing Parcels dataset, and were validated with aerial and street imagery and information from the City of Cambridge Property Database.

Parameter	Mixed-Use Block	Residential Block
Avg. Building Age (years)	≥100	≥120
Avg. Building Height (stories)	2-3	2-3
Max. Building Height (stories)	10	3

3.2 Existing Building Typologies

Existing building characteristics from the two Resilient Urban Blocks were used to establish three building typologies for a more detailed assessment of potential energy resiliency actions: double/triple-deckers (i.e., one- to three-family residential buildings), multifamily residential buildings, and commercial office and retail buildings. Characteristics evaluated include typical age and construction type, mechanical systems, and ownership structure.

3.2.1 Double/Triple-Deckers

The double/triple-decker typology represents residential buildings with between one and three dwelling units. Based on an evaluation of double-triple-deckers within the two Resilient Urban Blocks, these buildings typically range from 1,000 to 4,000 square feet in total area, and from two to three stories in height. Many of the double/triple-deckers evaluated, and throughout Cambridge as well, were constructed prior to the 1900s.

Figure 12 – Examples of double/triple-deckers in The Port (credit: City of Cambridge)

Double/triple-deckers are typically of wood frame construction with vinyl or wood siding. Gable or mansard roofs covered with asphalt shingle are common, although some larger buildings have flat built-up roofs. Many of these buildings have little to no insulation at the foundation, walls, and ceilings. Heating is typically provided with a gas or fuel oil boiler located in an unfinished basement, connected to a hydronic distribution system. Central air conditioning is not common, and cooling is typically provided with window air conditioning units, if at all.

3.2.2 Multifamily

The multifamily typology represents residential buildings with more than three dwelling units. Based on the multifamily typologies evaluated within the two Resilient Urban Blocks, these buildings are typically 5,000 to 25,000 square feet in area and three to four stories in height. Many of the multifamily buildings evaluated were built in the 1930s or earlier.

Figure 13 – Examples of multifamily residential buildings in The Port (credit: City of Cambridge)

Multifamily residential buildings are typically wood frame or unreinforced masonry construction. Wood frame residential buildings resemble a larger version of the double/triple-decker typology described earlier. In both cases, a flat membrane or built-up roof is common. The wood frame version of this typology, similar to double/triple-deckers, has little to no insulation at the foundation, walls, and ceilings. Although typologies of masonry construction may also lack insulation, the brick and air cavity between exterior and interior walls results in slightly better thermal performance. Heating is typically provided with a gas or fuel oil boiler connected to a hydronic or forced air distribution system. Cooling is typically provided with window air conditioning units, although in some cases buildings or individual condo units have been recently renovated with a central air conditioning system.

Figure 14 – Examples of newer multifamily buildings in The Port (credit: City of Cambridge)

New or significantly altered multifamily buildings (i.e., those constructed or last altered prior to 2000) are typically larger, with 10 to 20 or more dwelling units, and are constructed to high standards of performance. Higher-efficiency heating and cooling systems are common, and heat and hot water is provided by a gas boiler located in the basement. High-efficiency windows and insulation are also common, and these buildings may be constructed to LEED standards. In some cases, rooftop Solar PV or solar hot water systems may be present.

3.2.3 Commercial Office and Retail

The commercial office and retail typology represents a range of building uses, ages, and configurations. To provide some measure of additional specificity, this typology was subdivided into commercial office and retail components. Commercial office buildings evaluated within the two Resilient Urban Blocks range from 1,000 to 80,000 square feet in area, and from four to 10 stories in height. The commercial retail buildings evaluated were typically smaller, ranging from 1,000 to 40,000 square feet in area and one to three stories in height.

Figure 15 – Examples of commercial office and retail buildings in The Port (credit: City of Cambridge)

The Commercial Office and Retail typology typically has a flat roof, a portion of which may be occupied by mechanical equipment. Large office buildings generally integrate parking at portions of the ground floor and some upper floors. These buildings have varying degrees of insulation, depending on the time of construction. As mentioned earlier, mechanical equipment may be located on the roof, typically in buildings with forced air heating and cooling systems. Smaller office and retail buildings typically do not have centralized cooling, but rather window AC units or ductless split systems (i.e., ASHPs).

4 Existing Building Energy Resilience

The energy resilience strategies for existing buildings identified in this Memo are based on those developed for the Alewife Preparedness Plan, and updated or expanded to incorporate additional analysis and conditions specific to The Port. The Resilient Urban Blocks and building typologies were used to test these strategies at a building and block scale, and evaluate the potential challenges and benefits created.

It was found that the recommended actions for energy resilience create significant opportunities for reducing energy consumption and GHG emissions, and may likewise benefit from City and State policies and incentive programs for energy efficiency and clean energy implementation.[36] However, there are numerous challenges associated with existing building retrofits. In terms of technical feasibility, older buildings may require new electrical service for high efficiency electric heating and cooling systems. Structural retrofits may also be necessary to provide sufficient capacity to support the additional load of a rooftop solar photovoltaic (PV) system. However, in terms of general implementation, the greatest challenges typically involve aligning the interests of building owners, condo owners, and rental tenants.

4.1 Strategies for Existing Buildings

Strategies and actions for existing building energy resilience are provided in Table 4 on the following page. As previously mentioned, these strategies build from those established for the Alewife Preparedness Plan, and focus specifically on Flood Protection and Heat Protection. Actions developed specifically for The Port Preparedness Plan are indicated and shaded in grey.

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[36] See Section 2.2 of this Memo for a summary of relevant policies and programs.

Table 4 – Energy resilience strategies for existing buildings

	Strategy	Action	Implementation	Benefits	Implementation Considerations
B3	**Flood Protection for Existing Buildings**	Elevate critical building systems	Elevate or protect vulnerable utilities such as fuel storage, furnaces, and electrical panels above the 2070 10-year flood elevation.	Minimizes flood damage, lessened need to retrofit later due to increasing flood risks.	Split incentives between owners and renters. Lack of space on upper floors. Structural retrofit may be needed for equipment relocated to building roof.
B	**NEW**	High-efficiency electric heating and cooling	Replace equipment with high-efficiency electric heating and cooling systems that exceed ENERGY STAR requirements.	Requires less floor area within building; more feasible to install at higher elevations. Reduced energy consumption and GHG emissions.	Eligible for rebates and incentives, including financing. Vulnerable to outages if no back-up power provided. In-unit systems may be more feasible for condo owners.
B4	**Heat Protection for Existing Buildings**	Solar PV with energy storage	Install solar power with storage capabilities sufficient to provide two (2) consecutive days at 24 hrs./day of backup power or as required by LEED v4 for backup generation.[37]	Improves passive survivability. For a typical building, renewable energy would offset 8-12% of annual energy consumption and 12-14% of GHG emissions.	Eligible for rebates and incentives, including financing. Potential issues with permitting and approvals. Possible to integrate with microgrid or community energy system.
		High performance building envelope	Require minimum R-20 wall insulation, R-40 roof insulation, maximum of U-0.3 glazed windows, and limit air leakage to less than or equal to 3 ACH at 50 pascals	Improves passive survivability. For a typical residential building, enhancements would result in an estimated 50-60% reduction in annual energy consumption, and a 40-50% reduction in total GHG emissions.	Eligible for rebates and incentives, including financing. Difficult to implement in buildings with multiple tenants, although single-unit upgrades may be possible for condo owners.

Note: Strategies are ordered as presented in the CCPR Handbook and the order of presentation is not indicative of their relative importance.

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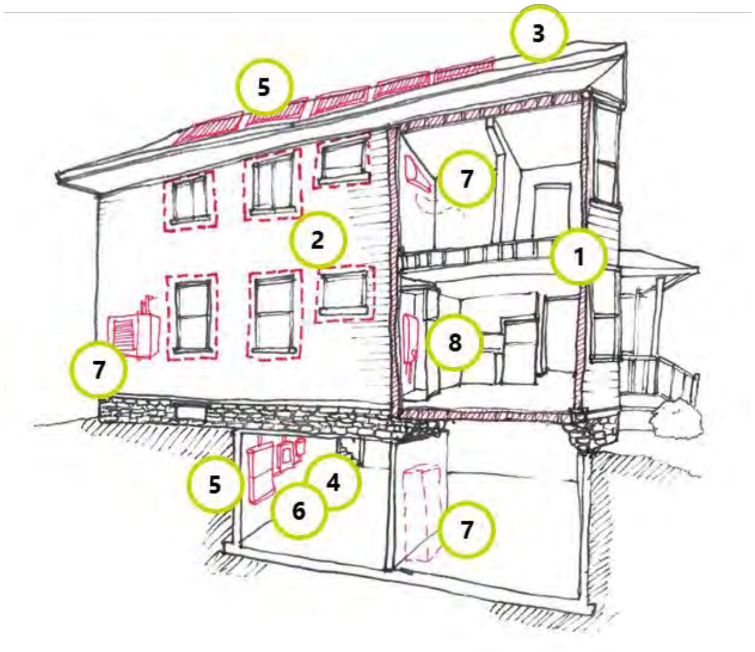
[37] U.S. Green Building Council, LEED v4, LEED BD+C: New Construction, Passive Survivability and Back-up Power During Disruptions. https://www.usgbc.org/credits/passivesurvivability

4.2 Prototype Projects

Two prototype projects were created to evaluate and further illustrate the aforementioned energy resilience strategies using the double/triple-decker and commercial office typologies identified for The Port. The relative cost, level of difficulty, estimated energy and GHG emissions reductions, and implementation timeframe were qualified to provide a high-level understanding of the potential challenges and complexity of each recommended energy resiliency action. The methodology and assumptions that were used for this evaluation are described in Section 7 of this Memo.

4.2.1 Double/Triple-Decker Energy Resilience Retrofit



1. Upgrade windows and insulate roof, basement, and exterior walls
2. Perform air sealing for new windows and exterior doors
3. Replace asphalt roofing with light-colored reflective shingles
4. Install sub-panel to isolate critical loads for backup power
5. Install solar PV on roof and battery storage to provide backup power
6. Replace and elevate utility meter, elevate main circuit breaker panel
7. Replace boiler with ductless mini-split system in each unit
8. Replace storage water heater with in-unit hot water systems

Figure 16 – Sketch of double/triple-decker prototype project

The double/triple-decker energy resilience retrofit prototype project include includes actions such as upgrading windows and insulation, replacing existing mechanical equipment with high-efficiency packaged units that serve each apartment, and installing solar PV and energy storage systems (Figure 16, Table 5).

Table 5 – Evaluation of double/triple-decker prototype project

	Action	Relative Cost	Level of Difficulty	Energy/GHG Reduction[38]	Implementation Timeframe
B3	Elevate or protect vulnerable utilities	Low	Low	-	Near-term
B (NEW)	Replace vulnerable equipment with high-efficiency electric heating, cooling, and DHW systems	High	High	111,000 kBtu (44%); 6.2 metric tons CO2e (38%)	Mid-term
B4[39]	Install solar power and energy storage systems	High	Medium	20,900 kBtu (8%); 2 metric tons CO2e (12%)	Mid-term
	Upgrade windows and insulation, and air-seal windows and doors	Medium	High	28,200 kBtu (11%); 1.5 metric tons CO2e (10%)	Near-term
	Upgrade roofing with reflective and/or light-colored materials	Low	Medium	1,700 kBtu (1%); 0.2 metric tons CO2e (1%)	Near-term

Note: Strategies are ordered as presented in the CCPR Handbook and the order of presentation is not indicative of their relative importance.

As demonstrated by this analysis, energy resilience actions can potentially result in considerable energy and GHG emissions reductions, in addition to improved passive survivability, backup power for critical loads, and protected mechanical equipment. The building envelope improvements specified would enable buildings to maintain stable indoor temperatures during winter storms and heat waves, whereas solar power and energy storage systems could be connected to a dedicated electrical panel for critical loads to provide backup power to specific equipment, appliances, or outlets (e.g., air conditioners) during outages.

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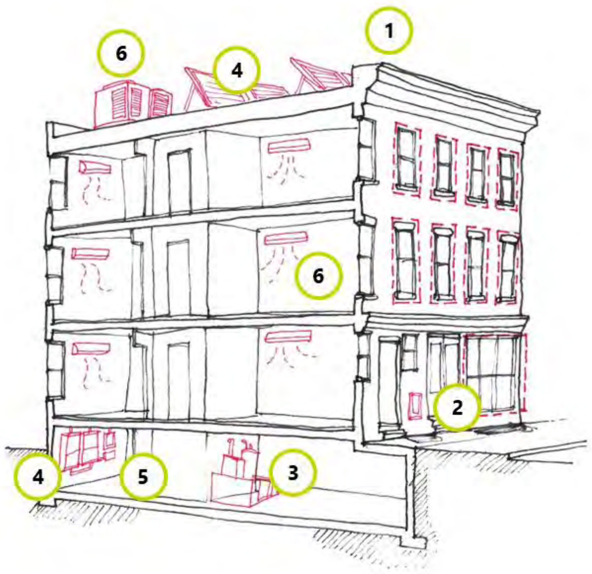
[38] All values estimated. Energy and GHG reductions calculated based on timeframe of implementation (e.g., the calculation of energy savings attributed to high-efficiency mechanical systems assumes that envelope upgrades have already been performed). See Section 8.1 of this Memo for methodology and assumptions.

[39] Resilience actions may be eligible for City or State assistance, including rebates and financing.

4.2.2 Commercial Office Energy Resilience Retrofit



1. Apply or replace roofing with a reflective and/or light-colored coating
2. Install exterior hookups for temporary backup heat and power
3. Elevate or flood-proof mechanical and electrical equipment
4. Install cogeneration or solar and energy storage system to provide backup power
5. Install sub-panel(s) to isolate critical loads for backup power
6. Install VRF system for cooling; heating where possible

Figure 17 – Sketch of commercial office prototype project.

The commercial office energy resilience retrofit prototype project include includes the same actions as the double/triple-decker retrofit, although the approach to implementation and estimated energy and GHG reductions vary (Figure 17, Table 6).

Table 6 – Evaluation of commercial office prototype project

	Action	Relative Cost	Level of Difficulty	Energy/GHG Reduction[40]	Implementation Timeframe
B3	Elevate or protect vulnerable utilities	Medium	Low	-	Near-term
B (NEW)	Replace vulnerable equipment with high-efficiency electric heating, cooling, and DHW systems	High	High	1,200,000 kBtu (23%); 63.9 metric tons CO2e (15%)	Mid-term

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[40] All values estimated. Energy and GHG reductions calculated based on timeframe of implementation (e.g., the calculation of energy savings attributed to high-efficiency mechanical systems assumes that envelope upgrades have already been performed). See Section 8.1 of this Memo for methodology and assumptions.

	Action	Relative Cost	Level of Difficulty	Energy/GHG Reduction[40]	Implementation Timeframe
B4[41]	Install solar power and energy storage systems	High	Medium	606,200 kBtu (12%); 58.3 metric tons CO2e (14%)	Mid-term
	Upgrade windows and insulation, and air-seal windows and doors	Medium	High	605,000 kBtu (12%); 7.9 metric tons CO2e (2%)	Near-term
	Upgrade roofing with reflective and/or light-colored materials	Low	Medium	51,000 kBtu (1%); 2.7 metric tons CO2e (1%)	Near-term

Note: Strategies are ordered as presented in the CCPR Handbook and the order of presentation is not indicative of their relative importance.

Similar to the double/triple-decker energy resiliency retrofit, energy resilience actions may also result in significant energy and GHG emissions reductions. Unlike residential buildings, commercial building owners typically encounter fewer challenges implementing retrofit projects, and may have a greater incentive to provide energy resilience as a means of attracting tenants.

4.3 Energy Resilience for Urban Blocks

The methodology and approach used to calculate energy and GHG emissions reductions associated with each prototype project were applied across the two Resilient Urban Blocks described in Section 3.1 of this Memo to evaluate the combined benefits of energy resilience actions across a larger geography. Estimates for energy and GHG emissions reductions were only applied to buildings that were constructed prior to 2000 and had not been recently renovated, as it is unlikely that the energy resilience actions specified would be implemented where newer building systems were present.

Although the actual results of implementing energy resilience actions may vary considerably based on conditions such as building age, construction, and occupancy, the benefits of maximum implementation across the Mixed-Use Block could include:

- 11,480-14,581 MMBtu in energy savings if 88% of the Block’s existing buildings (i.e., those constructed or last renovated prior to 2000), in terms of total area, are upgraded with more efficient envelopes, cool roofs, high-efficiency electric heating and hot water systems, and solar

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[41] Resilience actions may be eligible for City or State assistance, including rebates and financing.

PV with better storage. This is equivalent to the annual energy consumption of about 55 typical triple-decker buildings.[42]

- 670-910 metric tons CO2e reduction in GHG emissions, equivalent to the emissions of about 200 cars over the course of a year.[43]

Likewise, the benefits of maximum implementation across the Residential Block could include:

- 3,800-4,550 MMBtu in energy savings if 85% of the Block's existing buildings (i.e., those constructed or last renovated prior to 2000), in terms of total area, upgraded with more efficient envelopes, cool roofs, high-efficiency electric heating and hot water systems, and solar PV with battery storage. This is equivalent to the annual energy consumption of about 15 triple-decker buildings.[44]
- 220-280 metric tons CO2e reduction in GHG emissions, equivalent to the emissions of about 60 cars over the course of a year.[45]

Detailed estimates for individual building typologies are provided in Table 7 for the mixed-use block, and in Table 8 for the residential block.

Table 7 – Estimated benefits of maximum implementation for the Mixed-Use Block

Building Type	Total Area (sf)	Annual Energy Consumption (MMBtu/yr)	Annual Energy Reductions (MMBtu/yr)	Annual GHG Emissions (mtCO2e/yr)	Annual GHG Emissions Reductions (mtCO2e/yr)
1-3 Family	44,200	3,720	2,480	240	150
Multifamily	81,600	5,220	1,591	330	90
Office	212,300	16,800	7,940	1,410	510
Retail	43,100	5,430	2,570	460	160
Total	**381,200**	**31,170**	**14,581 (47%)**	**2,440**	**910 (37%)**

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[42] Assumes 252,000 kBtu of energy consumed per year for a typical triple-decker building. Based on BH analysis of typical three-family residential buildings in Cambridge.

[43] Assumes 4.6 metric tons CO2e per year for one typical passenger vehicle (i.e., a car). Based on: United States Environmental Protection Agency (EPA), Office of Transportation and Air Quality, EPA-420-F-18-008, March 2018. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100U8YT.pdf

[44] See footnote 42.

[45] See footnote 43.

Table 8 – Estimated benefits of maximum implementation for the Residential Block

Building Type	Total Area (sf)	Annual Energy Consumption (MMBtu/yr)	Annual Energy Reductions (MMBtu/yr)	Annual GHG Emissions (mtCO2e/yr)	Annual GHG Emissions Reductions (mtCO2e/yr)
1-3 Family	45,600	3,830	2,460	260	150
Multifamily	37,900	2,590	1,730	170	100
Institutional	2,600	190	90	20	10
Retail	4,800	530	270	40	20
Total	**90,900**	**7,140**	**4,550 (64%)**	**470**	**280 (60%)**

The methodology and assumptions used for calculating annual energy and GHG emissions reductions are provided in Section 8 of this Memo.

5 New Building Energy Resilience

As previously mentioned in Section 3.2.2 of this Memo, newer multifamily residential buildings in Cambridge are generally built to high standards of energy efficiency. In 2009 the Cambridge City Council voted to adopt the Massachusetts Stretch Energy Code, which requires all buildings greater than 100,000 square feet in area, and supermarkets, lab buildings, or conditioned warehouses of any size constructed after 2010 to meet 2015 IECC and ASHRAE 90.1-2013 energy standards.[46]

Although this provides some measure of resilience in terms of passive survivability, without specific building and zoning regulations for resilience, new buildings may remain vulnerable to climate change risks. Moreover, the required standards may not apply to a large segment of new construction (e.g., buildings less than 100,000 square feet in area; of the two Resilient Urban Blocks studied, the largest single building was approximately 78,800 square feet in area) and, in terms of energy efficiency requirements, are relatively lax in comparison to standards such as Passive House.[47]

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[46] New York State Energy Research and Development Authority (NYSERDA), "ASHRAE 90.1 Appendix G/ PHIUS+/Passivhaus Comparison Evaluation for Multifamily Buildings," September 2017, Revised February 2018. https://www.nyserda.ny.gov/About/Publications/EA-Reports-and-Studies/Energy-Efficiency-Services-Reports

[47] City of Cambridge, Community Development Department, Stretch Energy Code. https://www.cambridgema.gov/CDD/zoninganddevelopment/sustainablebldgs/stretchcode

5.1 Strategies for New Building

Strategies for new building energy resilience in the Alewife Preparedness Plan included requirements for elevating vulnerable mechanical and electrical equipment to protect against flood damage, and obtaining passive house certification to improve passive survivability and protect against extreme heat. These strategies are also valid for The Port, and are most effective when implemented at the city scale. However, this Memo further refines those strategies, and provides two additional actions for The Port Preparedness Plan: requirements for high-efficiency electric heating and cooling (e.g., air source heat pumps), and solar PV and battery storage.

Strategies and actions for existing building energy resilience are provided in Table 9 on the following page. Actions developed specifically for The Port Preparedness Plan are indicated and shaded in grey.

Table 9 – Energy resilience strategies for existing buildings

	Strategy	Action	Implementation	Benefits	Implementation Considerations
B1	**Flood Protection for New Buildings**	Elevate critical building systems	Require all critical building systems in new buildings located above the 2070 10-year flood elevation.	Minimizes flood damage, lessened need to retrofit later due to increasing flood risks.	Potential conflict between State and local building codes, zoning. Loss of leasable floor area.
		High-efficiency electric heating and cooling	Require high-efficiency electric heating, cooling, and hot water systems (e.g., ASHPs) that exceed ENERGY STAR requirements in all new buildings.	Requires less floor area within building; more feasible to install at higher elevations. Reduced energy consumption and GHG emissions.	Eligible for rebates and incentives, including financing. Vulnerable to outages if no back-up power provided. Application of requirements; enforcement mechanism.
B2	**Heat Protection for New Buildings**	High-performance building envelope	Require certain new buildings to meet Passive House or similar requirements for building envelope performance.[48]	Improves passive survivability. Reduced energy consumption and GHG emissions.	Eligible for rebates and incentives, including financing. Application of requirements, enforcement mechanism.
		Solar PV with energy storage	Incentivize backup generation or energy storage to provide power for four (4) consecutive days at 24 hrs./day or as required by LEED v4 for backup generation.[49]	Improves passive survivability. Renewable energy source; reduces energy consumption and GHG emissions. May help manage peak load conditions.	Eligible for rebates and incentives, including financing. Potential issues with permitting and approvals. Possible to integrate with microgrid or community energy system.

Note: Strategies are ordered as presented in the CCPR Handbook and the order of presentation is not indicative of their relative importance.

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[48] Passive House Institute of the United States, PHIUS+ Certification Overview. http://www.phius.org/phius-certification-for-buildings-products/project-certification/overview

[49] U.S. Green Building Council, LEED v4, LEED BD+C: New Construction, Passive Survivability and Back-up Power During Disruptions. https://www.usgbc.org/credits/passivesurvivability

Although a prototype project was not developed and analyzed for new buildings, a typical new multifamily building constructed in accordance with these recommendations may include the following:

1. High performance building envelope and cool roof (e.g., to Passive House standards)
2. Heat recovery ventilation system
3. VRF heat pump and in-unit hot water systems
4. Solar PV on roof and battery storage to provide backup power
5. Sub-metered utilities and separate sub-panel for critical loads (above flood elevation)
6. Building energy management and demand response

These actions would likely result in significantly less energy consumption, and associated GHG emissions, compared to a new building constructed in accordance with the current Stretch Energy Code, in addition to providing greater energy resilience.

6 Neighborhood-Scale Energy Resilience

Neighborhood-scale energy resilience involves strategies for improving the resilience of energy supply and distribution at a scale larger than a single building. This Memo addresses neighborhood-scale energy resilience across The Port area, rather than the Resilient Urban Blocks previously evaluated, with a focus on “traditional” microgrids and community energy systems. In addition to resilience enhancements, both of the aforementioned systems can facilitate the adoption of renewable energy sources, modernize and relieve stress on local electricity distribution, reduce GHG emissions, and potentially energy costs, and improve business performance by mitigating potential losses resulting from power outages.

A “traditional” microgrid is a group of interconnected loads (i.e., buildings or other energy consumers) and distributed energy resources (DERs) (e.g., on-site solar panels or natural gas generators) with clearly defined boundaries that acts as a single, controllable entity and can connect and disconnect from the grid to operate and deliver power in both grid-connected and island mode.[50] Microgrids can provide both energy resilience and improved energy efficiency, in addition to numerous other co-benefits.

Microgrids are best suited for sites with a density of high-demand energy consumers that value reliable power, and critical facilities where increased energy resilience can be used to benefit the surrounding community, such as community facilities, hospitals, nursing homes, and pharmacies.

An alternative and potentially complimentary solution to the microgrid is the implementation of community energy systems. Community energy systems are networks of distributed energy resources (DERs), such as solar

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[50] The U.S. DOE Microgrid Exchange Group defines a microgrid as a group of interconnected loads and distributed energy resources (DERs) with clearly defined boundaries that acts as a single, controllable entity and can connect and disconnect from the grid to operate in both grid-connected and island mode. Similarly, the Massachusetts CEC defines community microgrids as “small, ‘islandable’ electricity, heat and/or cooling distribution systems that coordinate and distribute energy supplied from multiple generation sources to a network of independent public and/or private users in a spatially defined area.”

PV arrays, battery storage, and combined heat and power (CHP) units that can be virtually managed (as opposed to physically connected infrastructure) by a single central authority, typically through a cloud-based platform. Because of this, energy resilience is only available at the site of the generation source (e.g., at the building, rather than across all energy users), but costs, and technical and regulatory challenges are significantly less. Further, these systems allow community members to invest and reap the economic benefits of distributed generation (e.g., renters can invest in a solar PV system and receive a share of payment for energy generation).

Community energy systems can serve as the first step towards traditional microgrid implementation by creating distributed energy resource and establishing a managing entity. This can help reduce the cost of microgrid construction and provide more time for any ownership, financing, and regulatory challenges to be resolved.

6.1 Neighborhood-Scale Strategies

Strategies and actions for neighborhood-scale energy resilience are provided in Table 10 on the following page. As previously mentioned, these strategies build from those established for the Alewife Preparedness Plan, and focus specifically on clean energy systems. Two actions—for microgrids and community energy systems, respectively—were updated specifically for The Port Preparedness Plan and are indicated and shaded in grey

Table 10 – Neighborhood-scale energy resilience strategies

	Strategy	Action	Implementation	Benefits	Implementation Considerations
C9	**Clean Energy Facility**	Community Energy Pilot	Community energy pilot project in The Port area, targeting approximately 240,000 square feet of rooftop space across 23 City-owned buildings	Estimated 4,500 MMBtu of renewable energy produced annually, approximately 7% of the total energy consumption of the targeted buildings within The Port, and 430 mtCO2e GHG emissions offset, representing approximately 12% of the targeted buildings' and 0.03% of citywide GHG emissions.	Energy resiliency benefits limited to site of installation. Requires outreach to homeowners, small businesses and other local stakeholders.
		Parking PV Canopies	Rooftop solar PV canopies totaling approximately 22,000 square feet at Standard Parking and Technology Square garage.	Estimated 1,500 MMBtu of renewable energy produced annually for the two buildings identified, and 150 mtCO2e GHG emissions offset, approximately 0.01% of citywide GHG emissions.	Potentially high installation and maintenance costs. Eligible for renewable energy incentives. Possible to integrate with microgrid or community energy system.
		Microgrid Feasibility Study	Undertake a microgrid feasibility study and convene a working group with Draper, Alexandria, MIT, and Novartis to identify potential sites and partnerships.	Estimated 3,500 MMBtu of renewable energy produced annually, representing 0.3% of total energy consumption of the targeted buildings, and 330 mtCO2e GHG emissions offset, representing approximately 1% of the targeted buildings' and 0.02% of citywide GHG emissions.	High installation and maintenance costs. Unclear ownership, responsibilities. Potential regulatory barriers. Special consideration should be paid to ensuring that any microgrid provides equitable access to Cambridge residents

Note: Strategies are ordered as presented in the CCPR Handbook and the order of presentation is not indicative of their relative importance.

6.2 Prototype Projects

The Port area was analyzed to determine potential sites for microgrids and community energy systems, and evaluate the potential benefits of installing rooftop solar PV systems to offset all or a portion of building energy consumption. Potential locations for implementing these systems within The Port are shown in Figure 18.

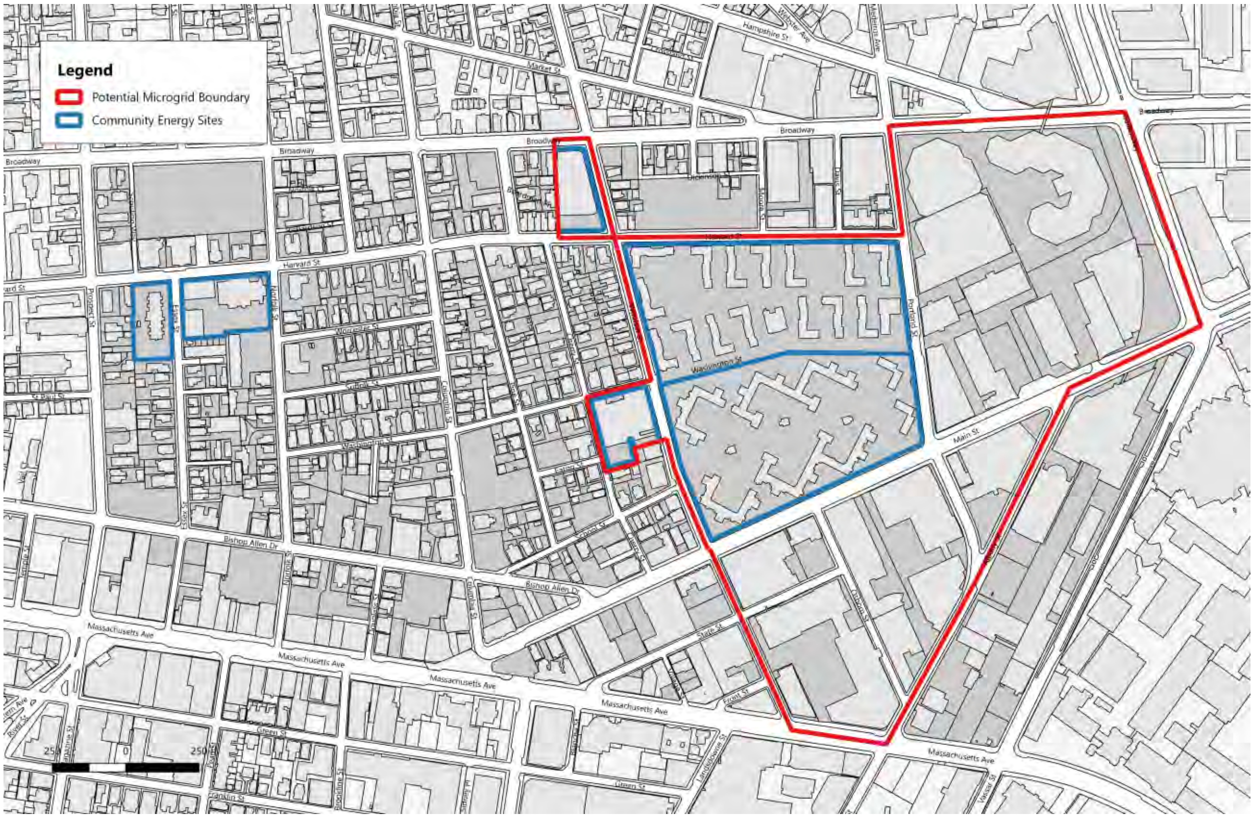

Figure 18 – Potential locations for microgrids and community energy systems within The Port

It was found that Solar PV installed as part of a microgrid and/or community energy system within The Port could produce more than 9,000 MMBtu of electricity, equivalent to the annual electricity consumption of about 150 typical triple-decker buildings.[51] This would offset approximately 910 metric tons CO2e of GHG emissions annually, which is equivalent to the emissions of about 200 cars over the course of a year.[52]

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[51] Note that this factor is for electricity, not energy consumption. Assumes 63,000 kBtu of electricity consumed per year for a typical triple-decker building. Based on BH analysis of typical three-family residential buildings in Cambridge.

[52] See footnote 43.

6.2.1 Microgrid Feasibility Study

Within The Port, the area with the most potential for microgrid implementation encompasses Draper laboratory and Alexandria's Technology Square, the Cambridge Housing Authority's Washington Elms and Newtowne Court apartment complexes, the Fletcher-Maynard Elementary School and the Cambridge Health Alliance, and MIT and Novartis facilities located Between Massachusetts Avenue and Main Street. Draper, Alexandria, MIT, and Novartis are ideal "anchor" customers with high energy demands and a need for reliable power. Fletcher-Maynard, the Cambridge Health Alliance, and certain Housing Authority facilities connected to the microgrid could serve as shelters for residents during storms, flooding, and extreme heat events.

A microgrid feasibility study would be needed to confirm these assumptions and facilitate the initial steps of microgrid implementation. Microgrid feasibility studies typically include the following steps:

1. **Set Goals:** Goals may include reliable energy supply, power to critical facilities, lower-cost power, or reduced carbon emissions.
2. **Engage Stakeholders:** Stakeholders include potential ownership/operating partners, microgrid customers, and funding/financing sources.
3. **Identify Sites:** Ideal sites include those with high demand users, a high density of diverse users, proximity to critical infrastructure, and access to energy (e.g., solar, wind, fuels).
4. **Evaluate Feasibility:** Feasibility considerations include technical constraints, project economics, type and availability of financing, ownership models, environmental and community impacts, and permitting needs.
5. **Implement:** Design, acquire financing, obtain permits/approvals, construct.[53]

It is critical to define and understand project goals early on in order to identify and develop the right microgrid solution. Goals may include a reliable and redundant supply of energy, back-up power to critical facilities, lower-cost power, or reduced carbon emissions. For The Port, goals would include the provision of resilient and renewable power sources to critical facilities within the area that could serve as a resource and shelter for community members during a prolonged power outage.

It is equally important to engage stakeholders that share these goals and understand the value that a microgrid system can create. This includes potential ownership and/or operating partners, microgrid customers, and entities able to provide funding or financing for the project, any of which may include the aforementioned property owners in The Port. It is typical for third parties to operate, maintain, or manage microgrid components, although large commercial (e.g., Novartis, which already operates a 5 MW cogeneration system) or institutional (e.g., MIT, which already supplies thermal and electric energy through a campus microgrid) property owners may serve in this capacity.

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[53] Pace Energy and Climate Center, "Community Microgrids: Smarter, Cleaner, Greener," 2013. http://nyssmartgrid.com/wp-content/uploads/Pace-Energy-and-Climate-Center-Community-Microgrids.pdf

The potential Microgrid boundary shown previously in Figure 18 was identified based on the small number of property owners with respect to the total land and building area covered, the diversity of potential customers (i.e., a mix of residential and commercial uses), the presence of high energy customers that would likely value energy resilience (i.e., research laboratories), and a relatively high potential for energy production through rooftop solar PV systems.

Once stakeholders and potential partners have been engaged, and a number of potential sites have been identified, a number of additional considerations must be addressed to further evaluate the feasibility of microgrid implementation:

1. **Technical:** Technical considerations are based on project siting, and include customer demand with respect to microgrid generation, prioritization of certain loads (e.g., critical versus non-critical loads) modes of operation (e.g., islanded versus grid-connected), matching customer and generation loads, and grid and end-user integration.
2. **Economic:** Economic considerations include project costs and potential revenue, and the cost of energy to microgrid users relative to their current rate structure.
3. **Financing:** Financing considerations include potential procurement and ownership structures (e.g., design-build versus design-build-own, operate, and maintain), the availability of capital, anticipated rate of return, and repayment terms.
4. **Ownership:** An effective ownership and management structure is critical to the success of a microgrid project. This will typically depend on the project financing structure, and may involve a cooperative or external party. The local electric utility may also have a role in managing, operating, or owning certain components of the microgrid system.
5. **Community:** Community considerations include public health (e.g., air quality improvements, construction impacts), equity (e.g., ability to pay higher rates for more energy resilience), and environment (e.g., GHG emissions).
6. **Regulatory:** Regulatory consideration include right-of-way issues, rate structures, permits and approvals, and supporting policies or incentives.

6.2.2 Community Energy Pilot

The Port is an ideal location for a community energy pilot project, as there are a number of larger buildings that are either City-owned and/or managed. Potential sites for installing community energy systems, specifically solar PV, include the Cambridge Housing Authority's Washington Elms, Newtowne Court, and JFK Apartments; the Prospect Hill Academy; the Fletcher-Maynard Elementary School; and the Cambridge Health Alliance.

The City of Cambridge could implement solar PV and energy storage systems at these facilities, and sell or confer "shares" of the system to residents living within The Port area. This would both enable residents in multifamily buildings (e.g., rentals, condos, and coops) to invest and benefit from solar PV (e.g., receive payments for the energy it generates and sells), and enhance the energy resiliency of City-owned facilities. Further, these community energy systems could eventually become integrated with and provide energy to a microgrid in the area.

Although community energy systems typically present significantly fewer implementation challenges than traditional microgrids (e.g., less construction, less permitting, lower implementation costs), many of feasibility considerations described previously for microgrids are still applicable. Stakeholder engagement is still an important step, as are those for establishing goals, identifying sites, evaluating technical feasibility, and implementation. It is also likely that the City would need to engage a third parties to install, operate, and/or maintain or manage these systems to achieve greater economies of scale and provide the most value to community energy customers.[54]

7 Precedents and Case Studies

7.1 Existing Building Energy Resilience

7.1.1 151-157 Allston Street LEED Multifamily Residential (Cambridge, MA)

151-157 Allston Street is a six-unit apartment building that was retrofitted after being damaged by a fire in 2015. The retrofit earned it the Platinum LEED-BD+C Homes certification.[55]

- **Area:** 10,250 square feet
- **Schedule:** Completed in 2015
- **Energy efficiency and design:** High-performance building envelope (R-26.5 insulated walls; R-50 roof); double pane, insulated argon-filled glazing with a low-E coating; LED lighting and controls (occupancy sensors; daylight sensors, etc.); ENERGY STAR appliances
- **Renewable energy:** Solar domestic hot water system; 9.81 kW solar electric system (30 rooftop solar PV panels)

7.1.2 Boston Design Center LEED Commercial (Boston, MA)

The Boston Design Center features dozens of showrooms for luxury interior furnishings. The building achieved Gold LEED-O&M certification in 2018 after implementing several energy efficiency initiatives.[56]

- **Area:** 350,000 square feet
- **Schedule:** completed in 2018
- **Energy efficiency and design:** replaced all windows with double pane energy saving windows; upgraded 80% of lighting to LED

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[54]

[55] https://homeownersrehab.org/green-development/allston-street ; http://www.gbig.org/buildings/1089669

[56] https://bostondesign.com/news/leed-gold-certification

- **HVAC systems:** upgraded from steam to hot water heating and from air-cooled to water-cooled HVAC units; new high efficiency boilers and boiler control systems

7.1.3 Harvard CGBC Headquarters HouseZero Retrofit (Cambridge, MA)

The Harvard Center for Green Buildings and Cities (CGBC) retrofitted its pre-1940s headquarters, now called HouseZero, targeting rigorous efficiency standards and performance goals, including almost zero energy required for heating and cooling and zero carbon emissions.[57]

- **Area:** 4,600 square feet
- **Schedule:** Completed in 2018
- **Energy efficiency and design:** improved envelope insulation level and airtightness; full natural ventilation (solar vents and cross ventilation systems); solar design features; daylighting
- **HVAC systems:** Through other passive design features and energy efficiency, the HVAC system could be removed and replaced with a single ground-source heat pump intended for peak (extreme) conditions
- **Renewable energy and storage:** rooftop solar PVs provide electricity for the heat pump and user equipment; battery used for night time use and low-sun conditions

7.2 New Building Energy Resilience

7.2.1 150 Second Street LEED Commercial (Cambridge, MA)

150 Second Street features laboratory and office space for biotech companies. The building achieved Platinum LEED Core and Shell certification.[58]

- **Area:** 123,210 square feet
- **Schedule:** Completed in 2012
- **Energy efficiency and design:** solar and daylighting controls
- **HVAC systems:** heat recovery loop, high-performance HVAC equipment
- **Energy performance:** 30% improvement over ASHRAE 90.1-2007

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[57] http://harvardcgbc.org/research/housezero/ ; https://www.dezeen.com/2018/12/03/snohetta-completes-ultra-efficient-housezero-at-harvard-university-in-massachusetts/

[58] https://www.usa.skanska.com/what-we-deliver/invest--develop/commercial-development/office_mixed-use/150-second/ ; https://www.high-profile.com/150-second-street-awarded-leed-cs-platinum-designed-by-elkus-manfredi/

7.2.2 300 Binney Street LEED Commercial (Cambridge, MA)

300 Binney Street features several uses including corporate offices, a daycare and preschool, and a fitness center. The building achieved Platinum LEED Core and Shell certification in 2014.[59]

- **Area:** 173,400 square feet
- **Schedule:** Completed in 2013
- **HVAC systems:** all heating and power needs are provided by Biogen's cogeneration facility (there is no direct connection to the utility grid)
- **Energy performance:** Designed to operate 38% more efficiently than the energy code required at the time

7.2.3 HRI Concord Highlands Passive House Residential (Cambridge, MA)

The Concord Highland Property is a new 98-unit affordable rental development. The building is designed to meet Passive House certification under the PHIUS+ 2015 system and will be the largest new construction, affordable housing project built in Cambridge in over 40 years.[60]

- **Area:** 125,000 square feet
- **Schedule:** comprehensive permit was approved in 2017
- **Energy efficiency and design**: high performance building envelope and cool roof
- **HVAC systems:** heat recovery ventilation system; VRF heat pumps and efficient central domestic hot water system
- **Renewable energy:** 83 kW rooftop solar PV; sub-metered utilities; separate sub-panel for life safety loads (above flood elevation)

7.3 Neighborhood-Scale Energy Resilience

7.3.1 Bronzeville Community Microgrid (Chicago, IL)

The Bronzeville Community Microgrid builds on the local utility's smart grid platform and a continuous effort to advance the design and performance of the electric system serving northern Illinois. The community was also interested in being at the forefront of energy innovation and resilience/security. The project was designed to advance the understanding of how microgrids can improve customer service.[61]

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[59] http://nerej.com/300-binney-street-certified-leed-platinum-core-shell

[60] https://homeownersrehab.org/about-our-properties/our-projects/new-acquisition-671-675-concord-ave

[61] Bronzeville Community of the Future; https://www.businesswire.com/news/home/20180228006367/en/ComEd-Approved-Build-Microgrid-Clusters-Nation; https://microgridknowledge.com/bronzeville-microgrid-chicago/; https://www.power-eng.com/articles/2018/11/bronzeville-building-the-first-utility-operated-microgrid-cluster.html

- **Energy source:** Solar PV and battery storage, diesel backup (and possibility of natural gas)
- **Schedule:** Project was approached by the Illinois Commerce Commission in Feb 2018; construction began June 2018; expected to be completed in 2019
- **Site selection:** Bronzeville was selected following a comprehensive study to evaluate locations where a microgrid could be located; the study developed an overall resiliency metric for small sections of ComEd's northern Illinois service territory and identified locations where a microgrid could best address both security and resiliency, with a focus on public good (the project will serve an area that includes 10 facilities providing critical services).
- **Capacity:** 7 MW aggregate load (Phase I: 2.5 MW load, solar PV and battery storage; Phase II: additional 4.5 MW load).
- **Customers**: Phase I: 490 customers; Phase II: 1,060 residential, commercial, and small industrial customers (College of Optometry, De la Salle Institute, Police HQ, Public Library, Nursing & Living Center, Care Centers, Math & Science Academy, Military Academy, and residential customers). The Bronzeville Community Microgrid will also connect with the existing Illinois Institute of Technology (IIT) microgrid, creating one of the first utility-scale microgrid clusters in the nation.
- **Funding sources:** $29.6M total project cost, including $14.7M for generation and $11.3M for distribution upgrades; $4M in US DOE grants (for the purpose of studying how microgrids support the integration of clean energy onto the grid and increase grid security); $600k from a partner.
- **Ownership:** Generation and storage will be owned by third parties (local utility, ComEd, issued two separate RFPs).

7.3.2 Northampton Microgrid (Northampton, MA)

The Northampton Microgrid came about as the City wanted to increase the resilience of three of its high priority emergency facilities after the 2011 Tropical Storm Irene and a massive October ice storm showed the vulnerability of the region's power system. [62]

- **Energy source:** Solar PV and energy storage; CHP (and possibility of natural gas)
- **Schedule:** Technical study began in 2014; work was expected to begin in 2015
- **Technical study:** Through the technical study, the City identified specific critical loads and an appropriate control strategy, verified the feasibility of interconnecting across the public way, identified an economically sized natural gas generation configuration or possible alternative on-site generation or storage at the hospital site, and determined the system benefits and impacts.
- **Customers**: Cooley Dickinson Hospital; Department of Public Works HQ; American Red Cross Shelter (at Smith Vocational and Agricultural High School); all three facilities have existing

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[62] https://www.gazettenet.com/Archives/2015/01/solargrant-hg-010714; http://nesea.org/sites/default/files/session-docs/lightning_in_a_bottle_ii_lotspeich.pdf; https://microgridknowledge.com/massachusetts-awards-18-4m-microgrids-energy-resiliency-projects/

backup generators that will remain in place; the microgrid will create an additional layer of redundancy and promote the use of renewable energy sources.

- **Funding sources:** Initial grant from the State's Community Clean Energy Resiliency Initiative funded the initial technical study; $3.1M from the State Department of Energy Resources (DOER) as part of the Resiliency Initiative (grant was expected to cover entire project cost).

7.3.3 Municipal Light Department Microgrid (Sterling, MA)

The Municipal Light Department Microgrid was built to provide emergency backup power to the town's critical facilities that provide first responder services in the event of a grid outage. The microgrid was also attractive to the town for its resiliency benefits, economic benefits, and the cost savings for ratepayers.[63]

- **Energy source:** Solar PV and energy storage system
- **Schedule:** DOER grant awarded in 2014; construction began in Fall 2016; project was completed and commissioned in December 2016
- **Capacity:** 2MW storage capacity; 2.4MW solar array
- **Customers**: Sterling police station and dispatch center, a community facility providing first responder services.
- **Benefits to ratepayers:** By discharging the batteries during hours of peak electricity demand, the Sterling energy storage project is expected to save the town's ratepayers at least $400,000 per year by decreasing costs associated with capacity and transmission charges from the regional power services supplier, ISO New England. Sterling will be able to lower its demand for grid services for the ISO by discharging the battery system during times of regional peak demand.
- **Funding sources:** $2.7M total project cost; received $1.46M grant from the State DOER (part of Resiliency Initiative); also received US DOE funding (under its energy storage demonstration program); project received additional support from Sandia National Laboratories, Clean Energy States Alliance (through its Energy Storage Technology Advancement Partnership), and Clean Energy Group's Resilient Power Project through a granny from the Barr Foundation.
- **Research:** A key feature of the project, which the DOE and Sandia National Laboratories are supporting, is to demonstrate and analyze the economic case for battery storage; the project is expected to pay for itself in just over two years (even without grants the payback period would have been fewer than seven years).
- **Ownership:** Owned by Sterling Municipal Light Department (SMLD).

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[63] https://www.cleanegroup.org/ceg-projects/resilient-power-project/featured-installations/sterling-energy-storage/ ; http://info.neces.com/sterling-announcement

8 Methodology and Assumptions

8.1 Existing Building Energy Resilience

The following methodology and assumptions were used to estimate potential energy and GHG emissions reductions associated with the existing building prototype projects described in Section 4.2 of this Memo.

8.1.1 Double/Triple-Decker Prototype Project

Key physical characteristics for the Double/Triple-Decker prototype provided in Table 11. The estimated energy use intensity (EUI) for this building type was multiplied by the prototype building area to establish annual energy consumption. The assumptions for end use energy consumption are provided in Table 12, which were used to estimate potential reductions in heating, cooling, domestic hot water (DHW), and other (e.g., appliances, lighting) loads.

Table 11 – Physical characteristics of the Double/Triple-Decker prototype

Parameter	**Value**
Site Energy Use Intensity (kbtu/sf/yr.)[64]	84
Total Area (sf)	3,000
Building Height (ft)	20
Building Footprint (sf)	800
Wall Area (sf)	2,400
Window to Wall Ratio	0.15

Table 12 – Estimated end use energy consumption for the Double/Triple-Decker Prototype

End Use	**Pct. Annual Energy Consumption**	**Annual Energy Consumption (kBtu/yr.)**
Heating	58%	146,460

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[64] Based on 2018 Cambridge Climate Action Plan “Buildings Model,” Three Family Residential Typology 2019 projected EUI.

End Use	Pct. Annual Energy Consumption	Annual Energy Consumption (kBtu/yr.)
Cooling	7%	17,640
DHW	17%	42,840
Other	18%	45,360
Total	**-**	**252,000**

The energy resilience actions for existing buildings enumerated in Section 4.1 of this Memo were modeled to avoid over-estimating the benefits of multiple, overlapping energy conservation measures (ECMs). This was achieved by first modeling energy reductions for building envelope improvements, and then modeling further reductions for improved heating and cooling systems based on that already-reduced value for energy consumption. As such, the estimated reductions in energy consumption are best understood holistically, rather than as individual actions.

The assumptions used to calculate heating, cooling, hot water, and building envelope improvements are provided in Table 13 for both the baseline and retrofit condition.

Table 13 – Baseline and retrofit assumptions for the Double/Triple-Decker prototype

Parameter	Baseline	Retrofit
Heating Efficiency	80%	2.9 COP
Cooling Efficiency	3.2 COP	3.7 COP
DHW Efficiency	80%	95%
Window U-Value	0.20	0.12
Wall R-Value	15	20
Roof R-Value	30	40
Infiltration Rate	0.8 ACH	0.6 ACH

An additional eight percent reduction in annual cooling energy was estimated for the implementation of a “cool roof,” which was based on a study of similar existing roofs in New York City, which were found to reduce annual cooling energy by 10-30 percent.[65] A conservative, eight percent reduction in annual cooling energy was assumed to account for heat gain attributed to solar PV installations.

Annual energy production for a solar PV system installed on the roof of the Double/Triple-Decker prototype was modeled based on an available roof area of 320 square feet and a 5 KW system size, which would offset approximately 46 percent of the annual baseline electricity consumption. This would result in a system that occupies approximately 22 square feet of rooftop space. These assumptions are provided in Table 14 below.

Table 14 – Solar PV system assumptions for the Double/Triple-Decker prototype

Parameter	**Value**
Solar Production Rate (kWh/kW/yr.)	1,225
Installed Capacity (kW)	5
Installed Area (sf)	320

Reductions in annual energy consumption, by action and ECM, for the Double/Triple-Decker prototype energy resilience retrofit are provided in Table 15 below.

Table 15 – Estimated reductions in annual energy consumption for the Double/Triple-Decker prototype

Action	**ECM**	**Annual Energy Reduction (kBtu/yr.)**	**Pct. Annual Energy Consumption**
Replace vulnerable equipment with high-efficiency electric heating, cooling, and DHW systems	Replace boiler with ductless mini-split system in each unit	116,367	46%
	Replace storage water heater with in-unit hot water systems	6,764	3%
Install solar power and energy storage systems	Solar PV only; energy storage not modeled	20,904	8%
	Upgrade windows and insulate roof,	12,617	5%

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[65] New York City Department of Small Business Services, “NYC CoolRoofs,” June 2017. https://coolroofs.org/documents/NYC_CoolRoofs_6-14-17_Presentation.pdf

Action	ECM	Annual Energy Reduction (kBtu/yr.)	Pct. Annual Energy Consumption
Upgrade windows and insulation, and air-seal windows and doors	basement, and exterior walls		
	Perform air-sealing for new windows and exterior doors	10,107	4%
Upgrade roofing with reflective and/or light-colored materials	Replace asphalt roofing with light-colored reflective shingles	1,411	0.8%
Total		**168,171**	**67%**

8.1.2 Commercial Office Prototype Project

Key physical characteristics for the Commercial Office prototype provided in Table 16. The estimated energy use intensity (EUI) for this building type was multiplied by the prototype building area to establish annual energy consumption. The assumptions for end uses energy consumption are provided in Table 17, which were used to estimate potential reductions in heating, cooling, domestic hot water (DHW), and other (e.g., appliances, lighting) loads.

Table 16 – Physical characteristics of the Commercial Office prototype

Parameter	Value
Site Energy Use Intensity (kbtu/sf/yr)[66]	79
Total Area (sf)	65,000
Building Height (ft)	45
Building Footprint (sf)	20,000
Wall Area (sf)	25,200
Window to Wall Ratio	0.10

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[66] Based on 2018 Cambridge Climate Action Plan “Buildings Model,” Office Typology 2019 projected EUI.

Table 17 – Estimated end use energy consumption for the Commercial Office Prototype

End Use	**Pct. Annual Energy Consumption**	**Annual Energy Consumption (kBtu/yr.)**
Heating	25%	1,283,750
Cooling	10%	513,500
DHW	3%	154,050
Other	62%	3,183,700
Total	**-**	**5,135,000**

The assumptions used to calculate heating, cooling, hot water, and building envelope improvements are provided in Table 18 for both the baseline and retrofit condition.

Table 18 – Baseline and retrofit assumptions for the Commercial Office prototype

Parameter	**Baseline**	**Retrofit**
Heating Efficiency	80%	2.3 COP
Cooling Efficiency	3.5 COP	3.7 COP
DHW Efficiency	80%	95%
Window U-Value	0.20	0.12
Wall R-Value	15	20
Roof R-Value	30	40
Infiltration Rate	1.0 ACH	0.6 ACH

An additional five percent reduction in annual cooling energy was estimated for the implementation of a “cool roof.” This is slightly less than the estimated eight percent for the Double/Triple-Decker prototype, as the benefits relative to the energy consumption of a larger, commercial building are likely to be less pronounced.

Annual energy production for a solar PV system installed on the roof of the Commercial Office prototype was calculated in the same matter as that for the Double/Triple-Decker prototype, although the output is significantly higher given the size of the prototype building. Assumptions for the Commercial Office prototype are provided in Table 19 below.

Table 19 – Solar PV system assumptions for the Commercial Office prototype

Parameter	Value
Solar Production Rate (kWh/kW/yr.)	1,225
Installed Capacity (kW)	145
Installed Area (sf)	9,280

Reductions in annual energy consumption, by action and ECM, for the Commercial Office prototype energy resilience retrofit are provided in Table 20 below.

Table 20 – Estimated reductions in annual energy consumption for the Commercial Office prototype

Action	ECM	Annual Energy Reduction (kBtu/yr.)	Pct. Annual Energy Consumption
Replace vulnerable equipment with high-efficiency electric heating, cooling, and DHW systems	Replace boiler with forced air system with VRF	1,138,924	22%
	Replace storage water heater with in-unit hot water systems	24,324	0.5%
Install solar power and energy storage systems	Solar PV only; energy storage not modeled	606,229	14%
Upgrade windows and insulation, and air-seal windows and doors	Upgrade windows and insulate roof, basement, and exterior walls	131,790	3%
	Perform air-sealing for new windows and exterior doors	503,290	10%

Action	ECM	Annual Energy Reduction (kBtu/yr.)	Pct. Annual Energy Consumption
Upgrade roofing with reflective and/or light-colored materials	Apply light-colored coating to existing membrane roof	25,675	1%
Total		**2,430,232**	**47%**

8.1.3 Projected Heating and Cooling Loads

Estimated baseline and post-retrofit heating and cooling loads were calculated based on historic and projected heating degree days (HDD) and cooling degree days (CDD) for Cambridge, MA, which are provided in Table 21. These factors account for the variability of temperatures across a given year. Climate projections provided by Kleinfelder were used to calculate 2030 and 2070 CDD and HDD values.

Table 21 – Historic and projected heating and cooling degree days for Cambridge, MA

Parameter	2019	2030	2070
Heating Degree Days (HDD)	5,573	4,877	2,348
Cooling Degree Days (CDD)	1,103	1,623	3,513

These values were used to establish a baseline and retrofit "heating index" and "cooling index" for both the Double/Triple-Decker and Commercial Office prototypes described in the previous two sections of this Memo, which are provided in Table 22 below.

Table 22 – Heading and cooling indices for baseline and retrofit prototype projects

Parameter	Heating Index (kBtu/HDD/yr.)		Cooling Index (kBtu/CDD/yr.)	
	Baseline	Retrofit	Baseline	Retrofit
Double/Triple-Decker	26	9	15	8
Commercial Office	230	45	466	323

These indices were assumed constant, and applied to the projected 2030 and 2070 HDD and CDD values to estimate future energy consumption with respect to climate change. Current and projected annual heating and cooling loads for the baseline and retrofit Double/Triple-Decker and Commercial office prototypes are provided in Table 23 and Table 24, respectively.

Table 23 – Projected heating and cooling loads for baseline and retrofit Double/Triple-Decker prototype

Parameter	**Annual Heating Load (kBtu/yr.)**		**Annual Cooling Load (kBtu/yr.)**	
	Baseline	**Retrofit**	**Baseline**	**Retrofit**
2019	146,160	48,413	17,640	8,922
2030	127,914	42,369	25,951	13,126
2070	61,567	20,393	56,175	28,415

Table 24 – Projected heating and cooling loads for baseline and retrofit Commercial Office prototype

Parameter	**Annual Heating Load (kBtu/yr.)**		**Annual Cooling Load (kBtu/yr.)**	
	Baseline	**Retrofit**	**Baseline**	**Retrofit**
2019	1,283,750	253,397	513,500	356,363
2030	1,123,494	221,764	755,446	524,270
2070	540,751	106,738	1,635,239	1,134,837

8.1.4 Greenhouse Gas Emissions

Greenhouse gas (GHG) emissions for natural gas and grid-purchased electricity consumption were calculated using the GHG emissions factors used in the 2018 Cambridge Climate Action Plan update, which are provided in Table 25.

Table 25 – GHG emissions factors for grid-purchased electricity and natural gas

Energy Source	**Emissions Factor (mtonCO2e/kBtu)**
Natural Gas	0.00005
Electricity (Grid-purchased)	0.00010

To calculate baseline GHG emissions, annual electricity and natural gas use was determined for each of the prototype projects based on their end use energy consumption and assumptions for fuel source (e.g., natural gas is used for heating and DHW, electricity is used for cooling). The aforementioned emissions factors were then applied to each fuel source. Annual baseline energy consumption and GHG emissions are provided for Double/Triple-Decker and Commercial Office prototypes in Table 26 and Table 27, respectively.

Table 26 – Baseline annual energy consumption by fuel type for the Double/Triple-Decker prototype

End Use	Fuel Type	Annual Energy Consumption (kBtu/yr.)	Annual GHG Emissions (mtCO2e/yr.)
Heating	Natural Gas	146,160	7.3
Hot Water	Natural Gas	42,840	2.1
Cooling	Electricity	17,640	1.8
Other	Electricity	45,360	4.5
Total		**252,000**	**15.7**

Table 27 – Baseline annual energy consumption by fuel type for the Commercial Office prototype

End Use	Fuel Type	Annual Energy Consumption (kBtu/yr.)	Annual GHG Emissions (mtCO2e/yr.)
Heating	Natural Gas	1,283,750	64.2
Hot Water	Natural Gas	154,050	7.7
Cooling	Electricity	513,500	51.4
Other	Electricity	3,183,700	318.4
Total		**5,135,000**	**441.7**

These values were then used to estimate reductions in annual GHG emissions resulting from the energy resilience retrofit prototype projects described in previous sections. Reductions in annual energy consumption, by action and ECM, for the Double/Triple-Decker and Commercial Office prototypes are provided in Table 28 and Table 29, respectively.

Table 28 – Estimated reductions in annual GHG emissions for the Double/Triple-Decker prototype

Action	ECM	Annual GHG Emissions Reduction (mtCO2e/yr)	Pct. Annual GHG Emissions
Replace vulnerable equipment with high-efficiency electric heating, cooling, and DHW systems	Replace boiler with ductless mini-split system in each unit	6.3	39%
	Replace storage water heater with in-unit hot water systems	0.4	2%
Install solar power and energy storage systems	Solar PV only; energy storage not modeled	2.0	12%
Upgrade windows and insulation, and air-seal windows and doors	Upgrade windows and insulate roof, basement, and exterior walls	0.6	3%
	Perform air-sealing for new windows and exterior doors	0.9	5%
Upgrade roofing with reflective and/or light-colored materials	Replace asphalt roofing with light-colored reflective shingles	0.1	1%
Total		**10.0**	**62%**

Table 29 – Estimated reductions in annual GHG emissions for the Commercial Office prototype

Action	ECM	Annual GHG Emissions Reduction (mtCO2e/yr.)	Pct. Annual GHG Emissions
Replace vulnerable equipment with high-efficiency electric	Replace boiler with forced air system with VRF	60.5	14%

Action	ECM	Annual GHG Emissions Reduction (mtCO2e/yr.)	Pct. Annual GHG Emissions
heating, cooling, and DHW systems	Replace storage water heater with in-unit hot water systems	1.3	<1%
Install solar power and energy storage systems	Solar PV only; energy storage not modeled	58.3	14%
Upgrade windows and insulation, and air-seal windows and doors	Upgrade windows and insulate roof, basement, and exterior walls	26.7	6%
	Perform air-sealing for new windows and exterior doors	33.9	8%
Upgrade roofing with reflective and/or light-colored materials	Apply light-colored coating to existing membrane roof	1.4	<1%
Total		**155.1**	**36%**

8.2 Energy Resilience for Urban Blocks

Estimated energy and GHG reductions for the energy resilience retrofit prototype projects described in Section 8.1 of this Memo were used to perform a high-level evaluation of the impact of such retrofits on the two Resilient Urban Blocks described in Section 3.1. Parcel data for FY2018 from the Cambridge Assessing Department was used to assign one of the following typologies to the individual buildings within each Block:

- 1-3 Family (e.g., single-family homes, double- and triple-deckers)
- Multifamily (e.g., residential buildings with more than three dwelling units)
- Office (e.g., commercial office buildings)
- Institutional (e.g., schools and government-owned buildings)
- Retail (e.g., smaller fast food restaurants, bars, and shops)

For each of the aforementioned typologies, annual baseline energy consumption was calculated based on the EUI values used to model buildings GHG emissions for the 2018 Cambridge Climate Action Plan update, which were applied to the total area for each building recorded by the Assessing Department.

Rather than separate building energy consumption into separate fuel sources, a blended GHG emissions factor was created based on the proportion of electricity to natural assumed for the energy resilience retrofit prototype projects described in Section 8.1.4 of this Memo, and were further extrapolated to account for differences in total floor area. The EUI values and emissions factors used are provided for each typology in Table 30 below.

Table 30 – Assumed EUI and blended GHG emissions factor by building typology

Building Typology	**EUI (kBtu/sf/yr.)**	**Blended Emissions Factor (mtonCO2e/kBtu)**	**Assumptions**
1-3 Family	84	0.00536	Based on prototype retrofit analysis
Multifamily	64	0.00408	Assumed 76% of 1-3 Family Emissions Factor
Office	79	0.00664	Based on prototype retrofit analysis
Institutional	74	0.00624	Assumed 94% of Office Emissions Factor
Retail	126	0.01063	Assumed 159% of Office Emissions Factor

Estimated annual energy and GHG reductions for the Double/Triple-Decker and Commercial Office prototypes were assumed for the multifamily typology, and office and retail building typologies, respectively. In cases where a building contained multiple uses, the dominant use in terms of floor area was assumed. These values are provided for each building typology in Table 31 below.

Table 31 – Estimated annual energy and GHG reductions by building typology

Building Typology	**Pct. Annual Energy Reduction**	**Pct. Annual GHG Emissions Reduction**
1-3 Family	67%	62%
Multifamily	67%	62%
Office	47%	36%

Building Typology	**Pct. Annual Energy Reduction**	**Pct. Annual GHG Emissions Reduction**
Institutional	47%	36%
Retail	47%	36%

The total annual reduction in energy and GHG emissions for both of the Resilient Urban Blocks are provided in Table 32 below. A building-by-building account of assumed typology, estimated annual energy consumption and GHG emissions, and estimated reductions for each are provided for the Mixed-Use Block and Residential blocks in Table 33 and Table 34, respectively, on the following pages.[67] It should be noted that existing buildings that were constructed or last renovated after 2000 were excluded from energy reduction calculations, as they were assumed to have a reasonable level of energy efficiency compared to older existing building stock.

Table 32 – Summary of annual energy and GHG reductions for the each Resilient Urban Block

Resilient Urban Block	**Annual Energy Reduction (kBtu/yr.)**	**Pct. Annual Energy Reduction**	**Annual GHG Emissions Reduction (mtCO2e/yr.)**	**Pct. Annual GHG Emissions Reduction**
Mixed-Use Block	14,581,000	47%	910	37%
Residential Block	4,550,000	64%	280	60%

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[67] The total energy and GHG emissions reduction values from these tables were rounded for use elsewhere in this Memo; energy reduction values represented in kBtu were rounded to the nearest thousandth, GHG emissions values represented in mtCO2e were rounded to the nearest tenth.

Table 33 – Individual buildings and assumptions/estimates for Mixed-Use Block annual energy consumption and GHG emissions

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr.)		Annual GHG Emissions (mtCO2e/yr.)		Assumptions
			Baseline	**Reduction**	**Baseline**	**Reduction**	
76-124	1,869	1-3 Family	156,996	97,399	10	5.5	
76-125	1,922	1-3 Family	161,448	100,161	10	5.7	
76-132	2,120	1-3 Family	178,080	110,479	11	6.3	
42-18	1,120	1-3 Family	94,080	58,366	6	3.3	
76-53	1,592	1-3 Family	133,728	82,964	9	4.7	
76-131	2,120	1-3 Family	178,080	110,479	11	6.3	
42-92	1,520	1-3 Family	127,680	79,212	8	4.5	
42-19	1,628	1-3 Family	136,752	84,840	9	4.8	
76-54	2,054	1-3 Family	172,536	107,040	11	6.1	
76-92	1,120	1-3 Family	94,080	58,366	6	3.3	
76-91	1,246	1-3 Family	104,664	64,933	7	3.7	
42-23	1,360	1-3 Family	114,240	70,873	7	4.0	
42-21	3,171	1-3 Family	266,364	165,250	17	9.4	

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr.)		Annual GHG Emissions (mtCO2e/yr.)		Assumptions
			Baseline	**Reduction**	**Baseline**	**Reduction**	
76-93	2,741	1-3 Family	230,244	142,841	15	8.1	
42-95	3,588	1-3 Family	301,392	186,981	19	10.6	
42-22	2,712	1-3 Family	227,808	141,330	15	8.0	
76-55	2,074	1-3 Family	174,216	108,082	11	6.1	
76-113	1,644	1-3 Family	138,096	85,674	9	4.9	
42-93	2,000	1-3 Family	168,000	104,226	11	5.9	
76-66	2,264	1-3 Family	190,176	117,983	12	6.7	
76-78	1,578	1-3 Family	132,552	82,234	8	4.7	
76-62	2,792	1-3 Family; Retail	234,528	145,499	15	8.3	Assumed 1-3 family
42-68	21,740	Multifamily	1,391,360	863,187	89	49.0	
42-57	6,514	Multifamily	416,896	258,639	27	14.7	
42-88	21,749	Multifamily	1,391,936	0	89	0.0	Excluded; constructed post-2000

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr.)		Annual GHG Emissions (mtCO2e/yr.)		Assumptions
			Baseline	Reduction	Baseline	Reduction	
42-98	22,576	Multifamily	1,444,864	0	92	0.0	Excluded; constructed post-2000
42-58	8,989	Multifamily; Retail	575,296	356,908	37	20.2	Assumed multifamily
42-94	792	Office	62,568	29,983	5	1.6	
42-70	78,834	Office	6,227,886	2,984,465	524	158.6	
42-70	62,480	Office	4,935,920	2,365,342	415	125.7	
42-97	65,384	Office	5,165,336	2,475,280	434	131.5	
76-52	4,833	Office	381,807	182,966	32	9.7	
76-49	N/A	Parking Lot	0	0	0	0.0	Excluded
76-89	N/A	Park	0	0	0	0.0	Excluded
76-135	N/A	Park	0	0	0	0.0	Excluded
42-81	2,760	Retail	347,760	166,650	29	8.8	
42-91	4,851	Retail	611,226	292,906	51	15.5	
42-33	35,502	Retail	4,473,252	2,143,627	375	113.6	

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr.)		Annual GHG Emissions (mtCO2e/yr.)		Assumptions
			Baseline	Reduction	Baseline	Reduction	
Total	**381,239**		**31,141,847**	**14,425,164**	**2,435**	**780**	

Table 34 – Individual buildings and assumptions/estimates for Residential Block annual energy consumption and GHG emissions

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr)		Annual GHG Emissions (mtCO2e/yr)		Assumptions
			Baseline	Reduction	Baseline	Reduction	
75-20	3,078	1-3 Family	258,552	160,403	17	9.1	
75-166	2,877	1-3 Family	241,668	149,929	15	8.5	
75-154	1,657	1-3 Family	139,188	86,351	9	4.9	
75-152	2,160	1-3 Family	181,440	112,564	12	6.4	
75-35	2,496	1-3 Family	209,664	130,074	13	7.4	
75-30	2,042	1-3 Family	171,528	106,414	11	6.1	
75-104	2,393	1-3 Family	201,012	124,706	13	7.1	
75-28	3,809	1-3 Family	319,956	198,498	20	11.3	
75-34	1,351	1-3 Family	113,484	70,404	7	4.0	

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr)		Annual GHG Emissions (mtCO2e/yr)		Assumptions
			Baseline	Reduction	Baseline	Reduction	
75-36	1,893	1-3 Family	159,012	98,650	10	5.6	
75-147	1,357	1-3 Family	113,988	70,717	7	4.0	
75-29	2,218	1-3 Family	186,312	115,586	12	6.6	
75-150	3,769	1-3 Family	316,596	196,413	20	11.2	
75-31	3,247	1-3 Family	272,748	169,210	17	9.6	
75-153	2,115	1-3 Family	177,660	110,219	11	6.3	
75-24	1,708	1-3 Family	143,472	89,009	9	5.1	
75-37	2,166	1-3 Family	181,944	112,876	12	6.4	
75-37	1,739	1-3 Family	146,076	0	9	0.0	Excluded; renovated post-200
75-151	3,568	1-3 Family	299,712	185,939	19	10.6	
75-33	2,560	Institutional	189,440	90,782	16	4.8	Church
75-39	11,748	Multifamily	751,872	466,455	48	26.5	
75-42	8,460	Multifamily	710,640	440,875	45	25.1	
75-41	5,382	Multifamily	344,448	213,692	22	12.1	

Building ID	Total Area (sf)	Building Typology	Annual Energy Consumption (kBtu/yr)		Annual GHG Emissions (mtCO2e/yr)		Assumptions
			Baseline	**Reduction**	**Baseline**	**Reduction**	
75-145	6,631	Multifamily	424,384	263,284	27	14.9	
75-146	5,673	Multifamily	363,072	225,247	23	12.8	
75-32	3,544	Retail Store	446,544	213,988	38	11.4	
75-128	1,301	Retail Store	83,264	51,656	5	2.9	
Total	**90,942**		**7,147,676**	**4,250,000**	469	**240**	

8.3 Neighborhood-Scale Energy Resilience

The Port area was analyzed to determine potential sites for microgrids and community energy systems, and evaluate the potential benefits of installing rooftop solar PV systems to offset all or a portion of building energy consumption. The fourteen sites identified in Table 35 were selected and assigned to certain neighborhood-scale systems based on ownership (e.g., owned by the City, or a major property owner in the area), use (e.g., community-based institutions), and available roof area.

It was assumed that some community energy sites could eventually become integrated into a physical microgrid system. Parking PV canopies, which are identified as a separate energy resilience strategy, are assumed to connect to a future microgrid system as well. However, the potential energy production cited in this Memo for accounts for this overlap by excluding sites designated for community energy or parking PV canopies from microgrid calculations.

Table 35 – Potential sites within The Port for microgrids and community energy systems

Site Name	Community Energy	Parking PV Canopies	Microgrid
Cambridge Health Alliance	Yes	-	Yes
Draper Laboratory	-	-	Yes
Fletcher-Maynard Elementary	Yes	-	Yes
JFK Apartments	Yes	-	-
MIT Cogeneration Plant	-	-	Yes
Newtone Court	Yes	-	Yes
Prospect Hill Academy	Yes	-	-
Prospect Hill Academy	Yes	-	-
Saint Mary of the Annunciation	Yes	-	-
Schlumberger-Doll Research	-	-	Yes
Standard Parking	-	Yes	Yes
Technology Square	-	-	Yes
Technology Square Garage	-	Yes	Yes

Site Name	Community Energy	Parking PV Canopies	Microgrid
Washington Elms	Yes	-	Yes

Annual energy production and associated offsets in annual GHG emissions resulting from solar PV systems installed across the 14 identified sites was calculated based on estimated available rooftop area and the solar production rate identified in Section 8.1 of this Memo. Annual energy consumption is based on data reported in accordance with Cambridge Building Energy Use Disclosure Ordinance (BEUDO) for the identified sites.[68] Annual GHG emissions are based on the emissions factor for electricity, which is also identified in Section 8.1 of this Memo.

Table 36 – Annual energy production and GHG emissions offset by neighborhood-scale solar PV systems

Action	Buildings	Annual Energy Consumption (MMBtu/yr.)	Annual Energy Production (MMBtu/yr.)	GHG Emissions Offset (mtCO2e/yr.)
Community Energy	23	62,400	4,500 (7%)	433 (12%)
Parking PV Canopies	2	1,900	1,500 (79%)	147 (89%)
Microgrid[69]	8	1,019,300	3,500 (0.3%)	333 (1%)
Total	**33**	**1,083,600**	**9,500 (0.9%)**	**914 (1%)**

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[68] City of Cambridge, Cambridge Building Energy and Water Use Data Disclosure 2016-2018, February 2019. https://data.cambridgema.gov/Energy-and-the-Environment/Cambridge-Building-Energy-and-Water-Use-Data-Discl/72g6-j7aq

[69] Microgrid estimates exclude solar PV installations attributed to community energy and parking PV canopies actions.