Feasibility of Resiliency & Sustainability in Residential Multi-Unit Buildings in Boston

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Introduction

The need for energy security has become very important for homes, as climate change, old infrastructure, and extreme weather could cause disruptions to the power grid leaving entire apartment buildings without any power. Long power outages would leave homes without any heat in the winter or air conditioning in the summer and essential appliances for basic daily needs. This would eventually turn the residence into an unlivable place. In such conditions, people would need to leave their home and go to shelters or a relative's house, or maybe a hotel, but if these places also rely solely on power from the grid, they might also be a part of the consequence.

Boston's building stock is predominantly composed of pre-1950s structures, constructed prior to modern energy efficiency codes [1]. These older buildings often exhibit lower insulation levels, reduced airtightness, and outdated, inefficient equipment, leading to greater energy consumption and higher greenhouse gas emissions compared to more contemporary structures. Furthermore, buildings in Boston account for 75% of the city's total greenhouse gas emissions [1], highlighting the pressing need to enhance energy efficiency within the local built environment. Key characteristics of Boston, such as its coastal location, dense population, aging building stock, community housing, and strong policy framework, make it a compelling focus for sustainability and resilience efforts.

For Boston's population of 650,000 people, 195,000 of them—around 30%--will experience an outage annually [2]. The average length for these outages is 4 hours 15 minutes, so that would be the benchmark time period for buildings to maintain their own power needs [3]. Visualization for this comparison for vulnerability can be found in Figure 11: Emissions Output Estimates per Unit for Selected Buildings.

As society looks forward to rebuilding the energy systems in the face of climate change, there is an opportunity to create new energy designs that can respond to a myriad of challenges at once. There is a need now for energy that is not just renewable, but also resilient, and equitable. Above other system designs for renewable energy, microgrids are uniquely positioned to fill this gap. Defined by the Department of Energy as a "group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity concerning the grid”, microgrids are distinguished by their ability to both connect to the larger electrical grid and operate independently when the grid fails [4]. This provides the participants in the microgrid with power throughout the average duration of an outage, ensuring vital services such as Wi-Fi, cellular service, lighting, and more are maintained in the face of future challenges.

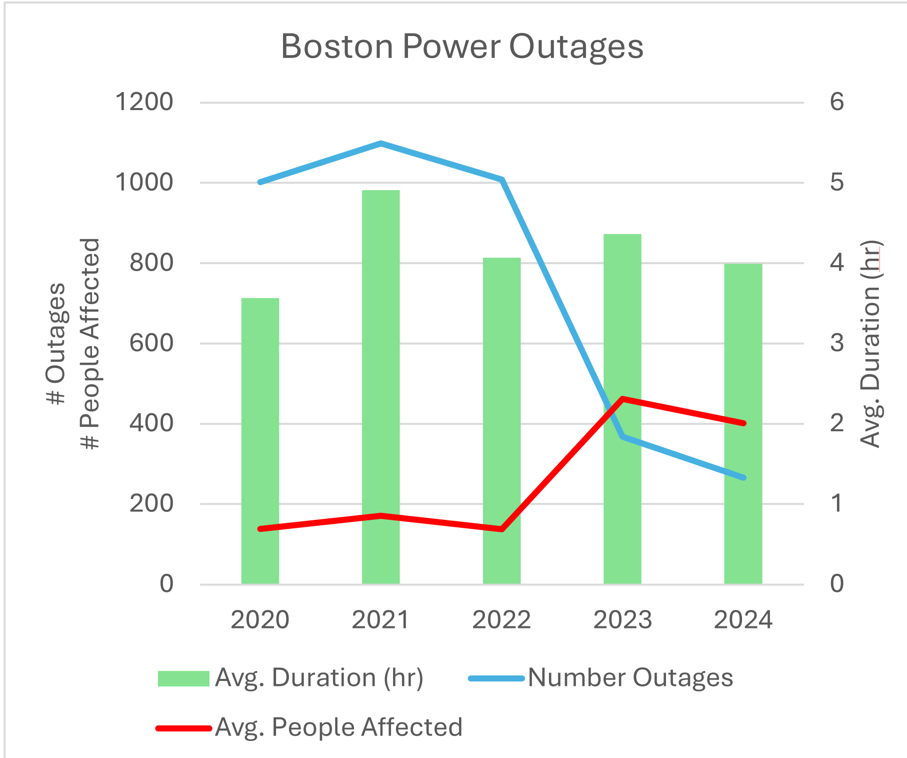


Figure 1: *Power Outages & Effects - Boston MA*

Power generation methods for microgrids can vary from site to site, but they often contain renewables and energy storage. By operating on both the supply and demand side of energy production, microgrids can provide and monetize several benefits that singular forms of renewables are unable to.

Often times in climate resilience conversations, ideas that can address multiple issues at the same time are suggested. Microgrids are one of these ideas because they can fill gaps left by other forms of renewable energy. Rooftop solar, for example, is beneficial in that it reduces our reliance on fossil fuels, but it is largely inaccessible to renters and low-income customers and does not in itself confer resilience. Similarly, community solar, while more accessible and equitable, fails to meet the resiliency needs that climate change will impose on communities.

Microgrid systems' financial and technical feasibility can be a solution to resiliency and sustainability that exists at the nexus of these challenges, providing key benefits to environmental justice communities, such as: resilience; cost savings; energy ownership and democracy; energy efficiency/home improvement; and an interest in addressing climate change. The financial and

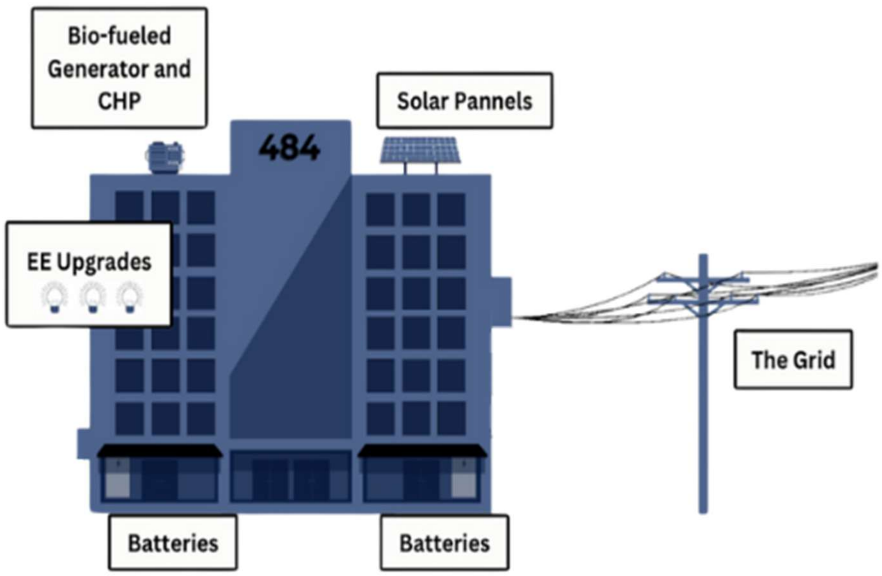


Figure 2: *Depiction of Microgrid Resilience System*

technical feasibility of microgrid systems has been explored in depth—the Department of Energy's "Microgrid Research and Development Program" and *Microgrid Knowledge* reports, as examples [[5], [6]]. With microgrids, we can envision an energy revolution where communities own their energy and where this energy is renewable, resilient, and affordable to all."

Energy efficiency can be significantly enhanced through Energy Conservation Measures (ECMs) that focus on retrofitting buildings with proper insulation, improved building envelopes, and window upgrades. These measures are essential in reducing energy losses associated with heating and cooling.

Research indicates that building envelope upgrades, including insulation and window replacements, can lead to a substantial decrease in greenhouse gas (GHG) emissions. For instance, a study on multi-residential buildings found that retrofitting with enhanced insulation and double or triple-glazed windows reduced operating GHG emissions by up to 90% [7]. Similarly, an evaluation of office building upgrades showed that improving airtightness and replacing windows contributed to a 45% reduction in total annual energy consumption, with net-zero carbon performance achievable through photovoltaic panels and solar heating [8].

Furthermore, deep energy retrofits incorporating energy-efficient building envelopes, heating and cooling systems, and renewable energy sources can lead to a 50% reduction in site energy use in most climates [9]. A study on city-scale residential buildings also found that tailored retrofit plans, including air conditioning system upgrades and insulation improvements, were crucial for enhancing energy efficiency and meeting carbon reduction goals [10].

Energy Conservation Measures (ECM) play a vital role in strengthening Microgrid systems, which further contribute to reducing GHG emissions and achieving net-zero targets by 2050.

Goal

The aim for this project is to assess the feasibility of increasing resiliency in multi-unit residential buildings Boston, MA, with considerations to sustainability and GHG emission reduction. This transformation should be facilitated through the implementation of various supportive policies, incentives, and regulatory frameworks designed to optimize the return on investment for these upgrades.

Objectives

Objective 1: Prepare an Energy Demand Profile of Multi-Unit Residential Buildings in Boston for the future:

- Examine the energy demand of buildings of different ages in Boston with a focus on seasonal weather variations, peak and average loads, time-of-use, and the energy inefficiencies present in residential apartment buildings. This analysis is essential for understanding and addressing energy consumption patterns effectively.

Objective 2: Feasibility Study of Energy Efficiency & Resiliency:

- Conduct a feasibility study and propose an energy system that enhances efficiency, resilience, and carbon-neutrality in buildings.

Objective 3: Analyze the viability of proposed energy systems with respect to regulatory framework policies & incentives.

- Identify policies, grants, and programs that financially incentivize energy efficiency and resilience improvements. Additionally, examine the regulatory framework that enforces sustainability and resilience standards, including penalties for noncompliance.

Tasks:

1. **Selection of multi-unit residential buildings in Boston MA;**
   - Identify three representative apartment buildings: one from before the 1950s, one from the midcentury period, and one modern building.

Deliverables:

- **List of the selected buildings -** Week 7 (March 3)

2. **Data Collection and energy use analysis:**
   - Gather details about the structural and energy systems, including data on electricity, heating, and cooling consumption.
   - Examine the trends in energy consumption throughout the different seasons.
   - Estimate greenhouse gas (GHG) emissions and assess carbon footprint.
   - Benchmark building energy performance against Boston's Building Emissions Reduction and Disclosure Ordinance (BERDO) standards. [11]

Deliverables:

- **Building energy profile report -** End of Week 9 (March 30).

  Preliminary data:
  - Residential Energy Consumption Survey (RECS) [12]
  - Estimated data on annual Heating Degree Days (HDD) and Cooling Degree Days (CDD). Energy star degree days calculator [13]
  - BERDO Reported Energy and Water Metrics [14]
  - Estimated carbon footprint by US EPA GHG emissions calculator [15]

3. **Examine the feasibility of Energy Conservation Measures and their impact on energy efficiency:**
   - Assess the potential for retrofitting the building by examining the following areas: insulation, HVAC systems, airtightness, and window upgrades.
   - Study the impact of highly efficient appliances & lighting.

Deliverables:

- **Proposed efficiency improvement strategies with expected impact on consumption -** Week 11 (April 7th)

4. **Assess the feasibility of microgrid systems with integrated renewable energy**
   - Assess feasibility of solar based on roof space and solar potential
   - Assess financial feasibility of heat pumps (air source and geothermal)
   - Assess energy feasibility of wind energy in urban small scale
   - Compare different energy system configurations with battery storage

Deliverables:

- **Report on Microgrid systems with integrated renewable energy -** Week 12 (April 14th)

  Preliminary data:

  - Annual PV system energy generation report by PV Watts [16] & financial outlook of a PV system
  - Global Wind Atlas Mean Wind Speed Data [17]
  - Massachusetts Electricity Profile [18]

5. **Examine the policies and the regulatory framework supporting energy efficiency and resiliency upgrades**
   - Identify codes & legislation supporting more resilient, sustainable buildings to encourage adoption of outline upgrades
   - Identify state and federal clean energy policies, like the Massachusetts Clean Energy Standard (CES) [19]
   - Assess Boston's climate action targets related to energy resilience.

Deliverables:

- **Policy overview report -** End of Week 7 (March 9)

  Preliminary data:

  - Resilient Mass program [20]
  - Article 88; Zoning laws for wind energy facilities in Boston [21]
  - Building Emissions Reduction & Disclosure Ordinance (BERDO) [11]
  - Article 37; city of Boston [22]

- Climate resiliency review policy [23]

6. **Compile financial incentives and strategic outlook for energy efficiency and resilience upgrades:**
   - Identify rebates, tax credits, and grants for energy retrofits.
   - Research Massachusetts-based funding programs; SMART, Connected-solutions, and BRIC.
   - Examine Property Assessed Clean Energy (PACE) & Energy Savings Performance Contracting (ESPC) financing options.

Deliverables:

- **Financial report of renewable energy configuration plans -** By end of Week 12 (April 20th)

  Preliminary data:

  - Massachusetts Household Heating Costs [24]
  - Average Energy Prices, Boston-Cambridge-Newton [25]
  - SMART program [26]
  - PACE financing in Massachusetts [27]
  - Energy Savings Performance Contracting (ESPC) [28]

7. **Economic & ROI Analysis;**
   - Estimate projected cost savings from proposed energy efficiency measures.
   - Calculate payback periods for different renewable energy systems.
   - Compare upfront costs vs. Long-term financial benefits.

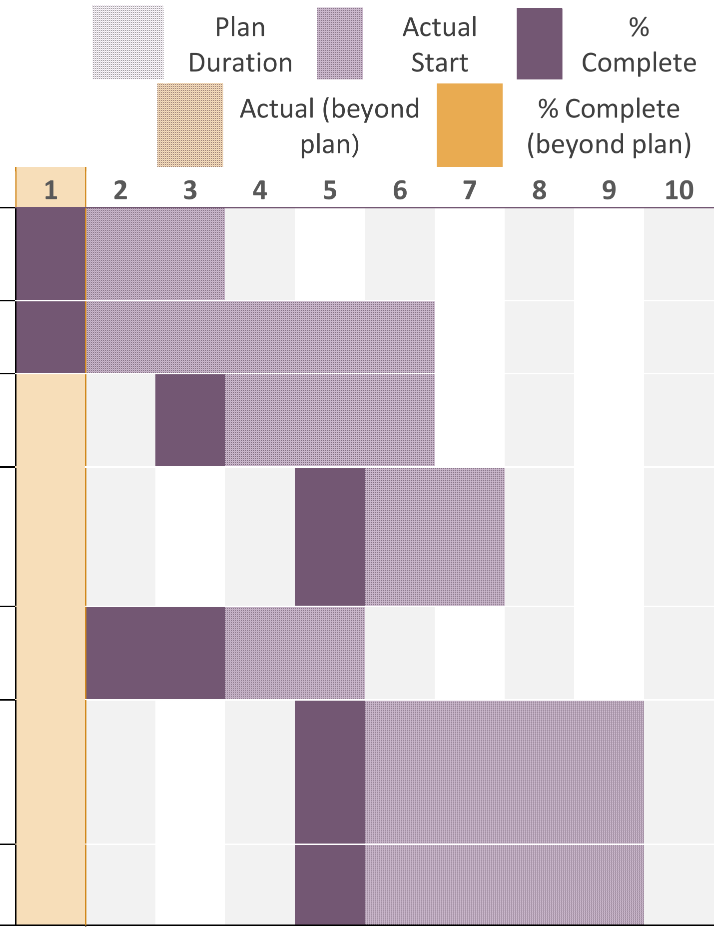
Deliverables:

- **Financial feasibility report with cost benefit analysis of proposed strategies -** By the end of week 12 (April 20th)

Initial Gantt Chart

Feasibility of Resiliency & Sustainability in Residential Multi-Unit Buildings in Boston

	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1	Selection of Multi-unit Residential Buildings	1	3	1	3	**35%**
2	Data Collection & Energy Use Analysis	1	6	1	6	**15%**
3	Energy Conservation Measures	3	4	3	4	**10%**
4	Microgrid Systems & Renewable Energy Integration Feasibility	5	3	5	3	**5%**
5	Policy & Regulatory Framework Analysis	2	4	2	4	**70%**
6	Financial Incentives & Strategic Outlook for Upgrade Implementation	5	5	5	5	**5%**
7	Economic & ROI Analysis	5	5	5	5	**5%**



Project Development:

Energy Demand Profile of Multi-Unit Residential Buildings in Boston:

Task 1: Selection of multi-unit residential buildings: *Pat Connell*

The three buildings we selected to investigate are fairly representative of many residential multi-unit buildings in Boston from the BERDO 2024 Reported Energy and Water Metrics dashboard [14] collected by *Tariq Anwar.*

The first building selected was 24 Mt. Vernon St. It was chosen as a representative pre-1950 building to showcase the contemporary energy profile of a building from that age. It was built in 1920 [29], which could limit its insulation, but being attached housing, the heat loss from the sides may be reduced. This also might hinder viability for rooftop solar as there is a tiered rooftop with windows (that tenants may want to use for sunlight and scenic views. 24 Mt. Vernon St. can be seen in Figure 3.

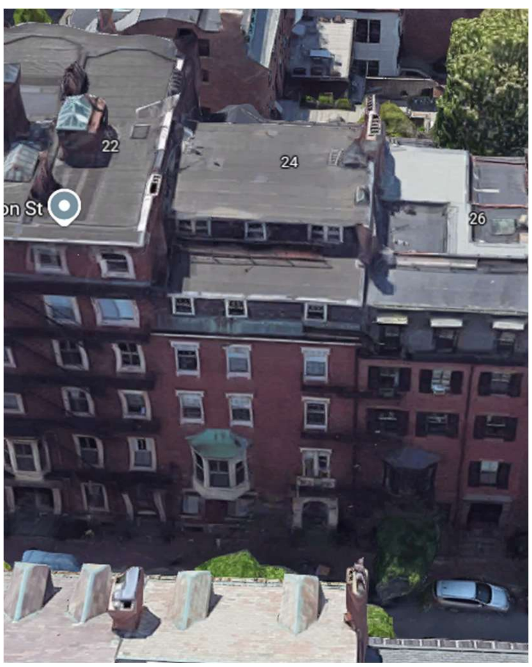


***Figure 3:** 24 Mount Vernon Street, Boston MA*

The second building selected was 624 Hyde Park Ave. It is a standard apartment building from 1963 [30], used to show what a multi-unit residential building from 1950-2000 might typically be like today, in terms of energy and resiliency. It is an unattached building with its lowest units being half underground. It is also seeming to need a roof repair—important to consider before installing anything on there. 624 Hyde Park Ave. can be seen in Figure 5.

60-66 Brainerd Rd. is a sizable modern apartment building. Built in 2012 [31], it stands out from the previous buildings by being operated explicitly by a realty group, advertised as “The Edge Allston”. It also stands out from 24 Vernon St. and 624 Park Ave. from its much larger size: 79 units as opposed to 20 and 24, respectively. One notable trait “The Edge” has is the air-handling units it has on the roof, meaning that its heating system is likely more up-to-date as well. 60-66 Brainerd Rd. can be seen in Figure 4.

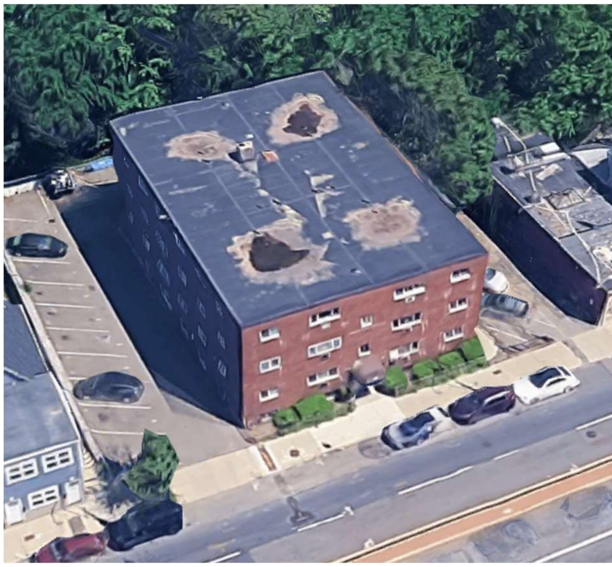


***Figure 5**: 624 Hyde Park Avenue, Boston MA*

***Figure 4:** 60-66 Brainerd Road, Boston MA*

These buildings all have a reasonably ample number of units, so neither their emissions per square foot nor per unit are skewed as much by variance.

Task 2: Data collection & energy use analysis: *Tariq Anwar*

Preliminary data has been accrued to make reasonable assessments of how different energy consumption and emissions for selected multi-unit residential buildings in Boston, by incorporating Heating and Cooling Degree Days, Boston home energy pricing trends, and BERDO reported energy performance data. The objective is to evaluate how seasonal variations impact energy use and emissions and to identify opportunities for efficiency improvements.

HDD & CDD Analysis: Seasonal energy demand impact HDD and CDD are critical indicators of seasonal energy demand. Higher HDD values correspond to increased heating requirements during colder months, while higher CDD values indicate greater cooling needs in warmer months. Table 1 displays the HDD & CDD variations in the months of January, July & October representing winter, summer & fall respectively and the reflected CO_2 emissions.

***Table 1:** Average HDDs & CDDs for Boston MA, 2022-2024*

Month	HDD (2024)	CDD (2024)	Total Energy Use (kBtu)	Total Emissions ($MTCO_2e$)
January	1071	0	Elevated (Peak Winter Heating Demand)	High CO_2 emissions
July	0	319	Increased (Peak Summer Cooling Demand)	Moderate CO_2 emissions
October	303	6	Moderate	Stabilized CO_2 emissions

During winter months, high HDD results in increased energy consumption and emissions due to heating demands, while summer months have high CDD which leads to elevated cooling loads but generally lower emissions than winter. Buildings with inadequate insulation such as the 24 Mount Vernon Street experience more pronounced seasonal variations in energy use.

BERDO Data; Energy use and emissions performance: Table 2 provides an insight into energy consumption and greenhouse gas emissions for the three selected buildings [11].

Table 2: *Energy Consumption and Emissions for Selected Buildings in Boston MA*

Building	Year Built	Energy Use Intensity (EUI) (kBtu/ft^2)	Total Energy (kBtu)	GHG Emissions ($MTCO_2e$)	Energy Star Score
24 Mt Vernon St.	1920	165.2	1,943,172.7	152.1	18
624 Hyde Park Ave.	1963	138	1,656,223.9	167.4	4
60-66 Brainerd Rd.	2012	46.7	2,994,712.1	85.2	98

It is visible that older buildings exhibit higher energy use per square foot (EUI). 24 Mt Vernon St; a pre-1950 building records the highest EUI at 165.2 kBtu/ft2 indicating significant energy inefficiencies due to outdated construction, whereas 60-66 Brainerd Rd. Representing a modern building maintains the lowest EUI at 46.7 kBtu/ft2 demonstrating superior energy efficiency. The total energy consumption is significantly influenced by the building size as the 60-66 Brainerd Rd. Reports the highest total energy use reflective of its larger floor area, regardless, the 24 Mt Vernon St. has disproportionately high energy consumption relative to its size which again reinforces the need for energy-saving interventions. Moreover, it is observed that the GHG emissions are higher in mid-century buildings. i.e. 624 Hyde Park Ave.

Table 14 shows that the electricity rates have risen sharply over recent years; as of January 2020, the electricity rates are displayed as \$0.232 per kWh, and as of January 2024 it is \$0.297 per kWh this reflects higher cooling costs. Natural gas prices peaked in the 2022-2023 period; as of February 2023, it costs \$2.341 per therm, reflecting higher heating costs. Rising energy costs disproportionately impact older, less efficient buildings, making energy retrofits and renewable energy integration a financially viable long-term investment.

Energy Efficiency & Resilience Feasibility Study:

Task 3: Energy Conservations Measures:

Ryan Faulkner

The first step in building sustainable options for an apartment building is to examine how much energy they use and look for ways to decrease that energy without affecting their way of life.

Many of the older buildings in Boston have energy inefficient lights, kitchen appliances, thermostats, and various other components that could be switched to a more efficient option without disruption to everyday life.

Table 3: *Decreasing Energy Usage in Boston MA Residential Buildings with Appliances*

Decreasing Energy Usage							
Buildings	Electricity Used per unit (kBTU/unit)	Electricity Cost ($)	Electric Emissions (kgCO2/unit)	Price With incentives ($)	Price per unit ($)	Energy Reduction (%)	New Energy Cost ($)
24 Mount Vernon St	9,224	895	1,135	13,000 - 36,000	650 - 1800	30.0	626.3
624 Hyde Park Ave	13,512	1,311	1,662	15,000 - 43,000	625 - 1790	30.0	917.4
60 Brainerd Road	10,554	1,024	1,298	52,000 - 142,000	660 - 1800	30.0	716.6

As can be seen in Table 3, when smarter appliances are used, energy use drops dramatically, which saves people a lot of money as well making the switch over an easy decision. To continue with sustainability and resiliency options, the first step is to use as little energy as possible, and these methods are an easy and cheap way to save money. Massachusetts has a goal of reaching carbon net zero by 2050, so they offer a lot of rebates and various other programs to help homeowners save money while investing in energy efficiency. The multifamily home efficiency rebate program can be used to save $2,000 on energy efficient upgrades, as long as the upgrades decrease the total energy use by 20% or more.

Another option to decrease wasted energy is to install air source heat pumps in each apartment. Heat pumps have become increasingly more popular each year for their incredible efficiency and simplicity. Heat pumps work by moving heat around, not generating it which is why they use so much less energy compared to their conventional counterparts. Heat pumps can be used to either heat or cool a home, it can move heat inside the home or it can be used to move heat outside effectively cooling the home during the summer months. Compared to natural gas, heat pumps are 2-4 times more efficient, in terms of energy input to heat output. Electric AC and heat pumps have a similar efficiency for cooling a home, but considering heat pumps are only one system that can be used to both heat and cool, its an easy decision to make. Mass save wants more heat pumps in use, which is why they offer $3,000 per ton of heating a heat pump can provide. For the apartment's being used in this study, they would need a 2 ton heat pump to be able to keep up with the heating and cooling needs. The federal government also has a $2,000 tax credit that can be applied when getting a heat pump. This would help customers save $8,000 per installed heat pump. The average price of installing an air source heat pump when there is already an HVAC system is only $8500, so with the rebate and federal tax credit it would only be $500 to install. As can be seen in the below graph, the payback period for these heat pumps is generally about 6 months. 60 Brainerd road has a slightly higher payback period because they are the most recently built residential buildings we were looking at, which means they likely already have a relatively efficient heating and cooling system.

Table 4: *Heat Pump Effectiveness*

Heat pumps							
Buildings	Energy Used for Heating/Cooling (Kbtu)	Current Price for Heating/Cooling ($)	Total Price of installing Heat Pumps ($)	With Mass Rebate and Federal Tax Credit ($)	New Price of Heating/Cooling ($)	Price Reduction (%)	Payback Period (years)
24 Mount Vernon St	1758693	46970	170000	10000	26622.8	40.0	0.491
624 Hyde Park Ave	1331744	51999	204000	12000	30219.7	40	0.551
60 Brainerd Road	2160945	86860	671500	39500	59006.8	30.0	1.42

Task 4: Microgrid Systems & Renewable Energy Integration Feasibility: *Pat Connell*

Resiliency in buildings is about achieving energy independence through integrating microgrids, where buildings or communities would be able to isolate from the power grid while continuing to fulfill their energy needs. Implementing a strategy balancing resiliency with sustainability and feasibility may foster strong, energy independent buildings and communities.

Sustainability here is about enacting emission-free power sources. We are assessing the feasibility of a few conventional strategies: roof-mounted solar photovoltaics (PV), wind energy at urban scale, and battery energy storage systems.

Solar: *Pat Connell*

As the solar PV is typically roof-mounted, the available roof area for each building was measured and compared against available solar irradiance throughout the year using PVWatts [16] to get an estimate on how much energy can be expected from ideal PV usage. The mean daily solar irradiance in Boston for each month can be seen in Figure 6 where irradiance is measured in amount of solar energy in kWh available per square meter each day.

Using the PVWatts software, the DC nameplate power could be approximated for each building by outlining available space on the roofs to place modules [32]. Then, combining this information with daily solar irradiance throughout the year, the annual energy production could be calculated, showing the energy produced to the variation of solar irradiance with system size.

Table 5 shows a summary of this data; more detailed calculations can be found in Appendix B: Energy Conservation Outlooks. System power ranges correspond to using 85-100% of available roof space and energy produced to the variation of solar irradiance with system size.

Table 5: *Solar PV System Size and Energy Generation by Site*

Address	DC Power (kW)	Annual Energy Produced (MWh)
24 Mount Vernon Street	9.3 – 10.9	11.1 – 16.0
624 Hyde Park Avenue	37.5 – 44.1	45.5 – 65.4
60 Brainerd Road	97.2 – 114.3	115.3 – 165.7

Wind: *Tariq Anwar*

Wind energy has also been a consideration for potential on-site energy generation. Using the preliminary wind energy data gathered from the Global Wind Atlas and comparing it with the area and heights that the buildings' roofs are at, the wind blows on average at 4-5.5 m/s [17]. This data, in conjunction with turbine and energy cost estimates, gives the opportunity to find the most suitable, practical conditions for turbine power generation.

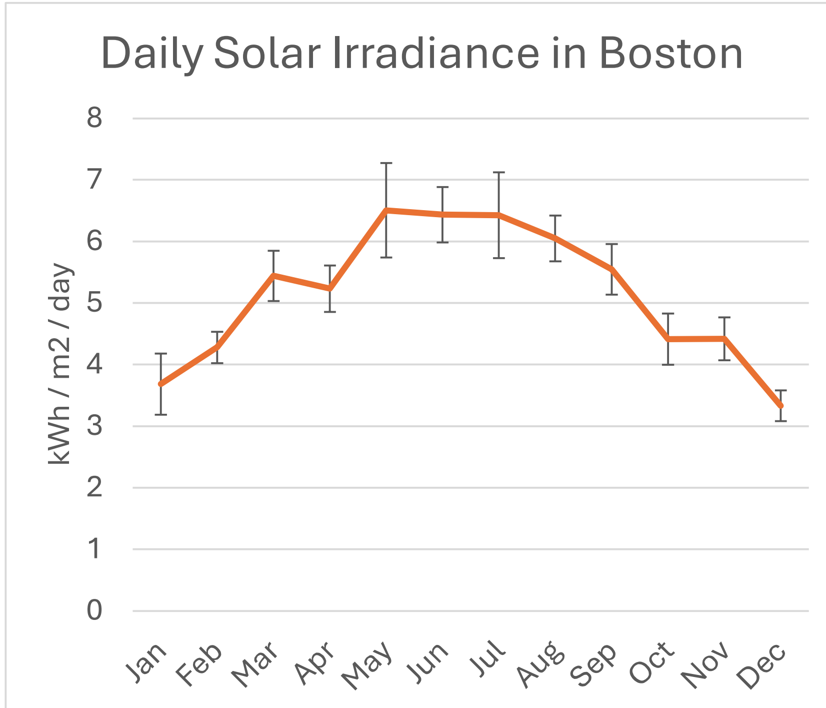


Figure 6: *Daily Peak Solar Hours in Boston MA*

Table 6 shows available wind turbines on the market along with their expected energy production across the range of wind speed averages.

Table 6: *Expected Turbine Energy Output for Varying Mean Wind Speed*

Name Plate Capacity	Est. Cost (USD)	Coeff. of Power (Cp)	Wind speed (m/s)	Energy Produced Annually (kWh)
50 KW [33]	$8,000 [33]	35%	4	3606
			4.5	5134
			5	7042
			5.5	9373

BESS: *Pat Connell*

As the sun is not always shining and the wind not always blowing, energy independence as a function of resilience should have a means of storing energy on site; we propose the installation of a Battery Energy Storage System (BESS). It would be designed to support the electric loads of the building in the event of a grid outage. The BESS could be charged through the grid connection, as well as the installed PV. The BESS should be sized to store 4 hours' worth of energy to satisfy each building's peak power needs, as well as meeting certain payback thresholds noted in Financial Incentives. Targeting 4 hours, 15 minutes' worth of energy storage is also sensible as, in the event of a major outage, there would be power reserves allowing some time to procure an alternative means of powering the building.

Table 7 shows the estimated size (in kWh) and power output (in kW) for a BESS at each building investigated in this project. Calculations for estimating each BESS's capacity and power output can be found in Appendix C: Energy Resiliency Strategies. Calculations were made based on changes in electricity demand after installation of ECMs, including heat pumps, appliances, and insulation/envelope improvements. BESS cost ($/kWh) was based on the quoted price of a Tesla Powerwall 3 [34]. The ranges in Table 7 was based on variance of electricity demand over the available years of BERDO data [14].

Table 7: *BESS Capacity and Power Output for Incentive-Based Storage Duration*

Address	Power Demand (kW)	4 Hour Capacity (kWh)	Min. Cost Estimate (k$)
24 Mount Vernon Street	15.6 – 19.0	66.1 – 80.8	$ 45.8 – 56.0
624 Hyde Park Avenue	15.7 – 19.2	66.7 – 81.6	$ 46.3 – 56.5
60 Brainerd Road	30.9 – 37.8	131.4 – 160.6	$ 91.1 – 111.3

Back-up Generator: *Pat Connell*

One consideration to be made in considering these strategies, however, is to compare how they perform relative to a more traditional means of building resilience: back-up diesel generators. Back-up generators are practical: they can be rented by an assortment of companies, and they can be fully energized with diesel in a moment as opposed to hours that BESS takes. But they are unfortunately not sustainable; they emit GHGs directly. There can be mitigations to this, though: using biodiesel (diesel that has been made from biowaste to some extent) over standard diesel will be closer to carbon neutral.

When comparing the effectiveness of a sustainable, renewable-based energy system to a diesel engine, it is important to look at cost and how it balances with emissions. Historically, the price of 20% biodiesel has matched very closely with standard diesel while 100% biodiesel has been 25% more expensive than the other two listed [35]. However, the alternative cost to this cheaper fuel source (standard diesel) is that it emits 3.3 times the amount of GHGs in its lifecycle as 100% biodiesel emits [36].

Based on assessed power demand of the buildings, estimates of fuel consumption, fuel costs, and CO2e emissions are shown in Table 8. An expanded version of Table 8 can be found in Appendix C. Costs of generator purchase and/or rental are not factored into these tables.

Table 8: *Diesel Generator Consumption, Costs, and Emissions for Selected Buildings*

Address	Diesel Use (gal/h)	Diesel Cost ($/h)	CO2e Emissions (kg/h)
24 Mount Vernon St.	0.405 – 0.495	1.47 – 1.80	1.10 – 1.35
624 Hyde Park Ave.	1.274 – 1.562	4.64 – 5.69	3.47 – 4.25
60 Brainerd Rd.	3.171 – 3.878	11.54 – 14.11	8.63 – 10.55

Policy, incentives & financial viability analysis:

Task 5: Policy & Regulatory Framework Analysis: *Pat Connell*

Legislative policies for both Boston in particular and Massachusetts at large aim to become net-zero emitters by the year 2050.

With BERDO, buildings in Boston of certain sizes and functions must disclose their energy use, resource consumption, floor area, and energy resilience amenities on-site (such as solar PV, community solar, BESS, and EV charging) to the city [14]. They will do this on an annual basis, starting in 2022, with the data being published the following year.

BERDO's emissions targets are based on annual CO2 equivalent emissions relative to floor area according to the building function; for residential multi-family housing, the current target is less than 4.1 $kgCO_2e/ft^2$ [37]. Compliance limits over time can be found in Table 9. In the case where buildings exceed the emissions standards for CO_2e emissions, an alternative compliance payment (ACP) will need to be made towards an Equitable Emissions Investment Fund for future decarbonization projects in Boston's environmental justice communities [37]. ACPs owed are $234 for every metric ton of CO2e emitted above a building's limit [37]. Savings for each building based on reducing BERDO-mandated ACPs through reducing emissions can be found in Table 19, Table 20, and Table 21.

The Clean Energy Standard (CES) is a state initiative for Massachusetts' power grid energy portfolio to be 100% renewable by 2050, and it is aiming to ramp up very quickly in the 2020s [38]. The CES coincides with the Clean Energy Portfolio Standard set for retail electricity suppliers, who will have to supply clean electricity at an increasing rate until 2050 [38].

Table 9: *BERDO Residential Allowed Net-Emission by Year (kgCO2e/ft2/yr)*

Amount of Units	2025-2029	2030-2034	2035-2039	2040-2044	2045-2049	2050+
15 – 34	-	2.4	1.8	1.1	0.6	0
35+	4.1	2.4	1.8	1.1	0.6	0

While not directly affecting residential buildings, the CES does affect the economics of home electricity. The increasing portion of renewables in the state portfolio compels the utility to purchase more from PV-sourced electricity [performed the Solar Massachusetts Renewable Target Program (SMART)], which allows income generation from PV electricity production [38].

Additionally, the utility companies will pay penalties for exceeding the limit of non-renewable energy they provide each year: $35 per MWh above the limit [38]. This penalty would then be passed on to the residential customers, increasing the future costs of grid-supplied electricity.

Task 6: Compile Financial Incentives and Strategic Outlook for Upgrade Implementation: *Tariq Anwar*

The analysis identifies strategic financial incentives available to support the deep retrofits of the proposed buildings with a focus on HVAC electrification, solar PV and storage, and envelope upgrades.

We are planning to adopt an approach where we understand how real projects have been financed and implemented would help us to assess the feasibility of energy upgrades in multi-unit residential buildings. Below, we present data from case studies of multifamily energy retrofit projects in Massachusetts, followed by strategic recommendations comparing these examples to the proposed upgrades for 24 Mt. Vernon St., 624 Hyde Park Ave., and 60-66 Brainerd Rd.

Table 22 lists the Incentive funded upgrades in Affordable Multifamily Housing; This table highlights the projects in which owners leveraged the utility and government programs (e.g. Mass Save, LEAN) to finance efficiency upgrades, often at no cost to the owner. These cases show the scale of savings possible when incentives cover a large share of costs.

These projects targeted lighting, insulation, HVAC, and appliances in affordable housing.

The TriTown Landing and Agawam projects received 100% up-front funding through Mass Save's low-income multifamily programs, resulting in zero net cost to owners [39, 40]. A substantial annual energy savings was realized in both cases. For e.g. 271,000 kWh/year of energy savings was recorded at TriTown [39]. Similarly, the Arlington *Chestnut Manor* retrofit (2023) was financed by a $1.3M investment from the utility (Eversource) and community agency (ABCD) [41], this covered installing modern heat pumps and triple-pane windows for elderly residents. These incentive-driven projects show how public programs can achieve deep reductions in energy use and costs for affordable housing without burdening owners with debt.

Table 23 lists the data on deep energy retrofits with multi source financing: This showcases larger, capital-intensive retrofits that achieved dramatic energy reductions greater than 50%. These were funded through various private financing, state/federal grants, and innovative programs, illustrating the scale of investment and savings for comprehensive upgrades including solar and electrification in multifamily residential buildings. Castle Square Apartments in Boston is a landmark retrofit that achieved a 72% energy use reduction after two-year, $8+ million upgrade (as a part of larger $50 million rehabilitation) [42, 43]. The project was financed via a combination of Low-income Housing Tax Credit (LIHTC) equity, state funding, and a HUD green Retrofit Program grant from American Recovery and Reinvestment Act of 2009 (ARRA) stimulus [43].

As a result, heating costs fell by approx. $144k/year and electricity costs by approx. $216k/year for this 500-unit affordable complex [43]. Similarly, Salem Heights Apartments (a 1970s era 28-unit high rise) has undergone a deep retrofit targeting passive house performance. This approx. $44.5M project is supported by Massachusetts' new *Climate Ready Housing Program;* a state bond-funded initiative providing grants for deep energy retrofits [44], alongside conventional affordable housing financing. It will wrap the building in super-insulation and switch to all-electric systems, aiming for 60% energy use reduction and significant long term cost savings [45]. These cases demonstrate that major capital investments, backed by public-private financing partnerships, can dramatically lower energy usage and emissions in multi-family residential buildings. These real time data can be used for comparative analysis to strategize the financing approaches for the selected buildings; 24 Mt Vernon St., 624 Hyde Park Ave., and 60-66 Brainerd Rd.

The energy system proposed in this report involves solar PV and battery energy storage systems plus some energy efficiency measures such as window upgrade, tight insulation and HVAC upgrade.

Mass Save offers a suite of rebates, incentives, and financing to encourage deep retrofits. A Home Energy Assessment virtually or in person is provided at no cost; an energy specialist identifies weatherization needs insulation, air sealing, etc. And help owners access rebates and financing [46]. Weatherization is very effective, it can reduce heating and cooling costs by up to 15-20% and Mass Save will cover 75-100% of approved insulation and sealing cost [46]. Assuming an Income eligible scenario, these proposed buildings except the 60-66 Brainerd Rd can receive these measures entirely free of charge [47]. A Mass Save Home Energy Assessment is typically required to qualify for these rebates and to unlock deeper incentives.

Mass Save also rebates heat pumps and other clean heating equipment. For **whole-home air-source heat pump (ASHP) installations** – where a heat pump replaces the existing boiler/furnace as the primary heating system – the rebate is **$3,000 per ton** of capacity (capped at $10,000 total) [48]. Notably, the whole-home rebate is available to **multifamily buildings** with 5 or more units (provided all requirements are met) [48]. If a heat pump is added as a supplement (keeping the old system as backup), a **partial-home rebate** of **$1,250 per ton** (up to $10,000) applies [48]. Partial-home installs must include integrated controls to manage dual systems [48]. All installers must be Mass Save participating contractors. In addition, Mass Save partners with retailers (e.g. Home Depot, Lowe's) to offer **$750 instant rebates** on qualifying ENERGY STAR heat-pump water heaters [49].

The Mass Save **HEAT Loan** program offers 0% financing (no interest) to make retrofits affordable [50]. Up to **$25,000** can be financed over the customer's lifetime for qualifying measures [50]. Eligible upgrades include attic and wall insulation, air sealing, ENERGY STAR windows* (when installed with weatherization) [50], heat pump systems, heat pump water heaters, and residential batteries (if enrolled in ConnectedSolutions) [50]. In practice, this allows owners to invest in envelope upgrades and electrification with zero-interest loans, to be paid back gradually.

Beyond utility programs, federal and state incentives further lower retrofit costs. The federal **Energy Efficient Home Improvement Credit** (IRA/Section 25C) provides **30% tax credits** on qualifying improvements [51]. In practice, this means up to **$2,000 per year** for heat pumps or heat-pump water heaters, and up to **$1,200 per year** total for building envelope improvements (e.g. insulation, air sealing, windows and doors) [51]. For example, the credit caps at $600 for all new exterior windows and $250 per exterior door [51]. Thus, a project combining a heat pump and envelope upgrade could claim both portions of the credit in the same year (up to $3,200 total) [51]. These federal tax credits apply through 2032 for eligible equipment installed after 2022.

At the state level, Massachusetts offers a **Residential Energy Credit** worth 15% of a home solar PV system's cost (capped at $1,000) [52]. This state solar tax credit applies to the owner's state income taxes and is in addition to the 30% federal solar investment tax credit. (The SMART program for solar used to pay production incentives, but available capacity is largely filled.) Other state programs include the Massachusetts ***High-Efficiency Electric Home Rebate Act*** (HEEHRA), which will provide up to **$8,000 per household** for heat pump installations in qualifying moderate-income homes (program rollout is pending).

Demand-Response incentives are available through Mass Save's ConnectedSolutions program. For example, homeowners who enroll smart thermostats on their heat pumps or central AC receive a **$50 signup bonus** and **$20/year** for each participating thermostat [53]. Likewise, home battery systems can earn **$275 per kilowatt-year** for their average dispatchable capacity during summer peak events (a typical 5 kW battery could earn ~$1,375/year) [53]. ConnectedSolutions also offers modest incentives for enrolling smart water heaters and other controllable loads. These payments both compensate participants and help the grid avoid higher peak generation.

24 Mt. Vernon St. (1920, 20 units): 24 Mt. Vernon St. is a pre-1950 building with a very high energy use intensity of approximately 165 kBtu/ft^2, relying on Fuel Oil 2 for heating. Due to its age and an inefficient envelope, the building experiences significant heat loss. Proposed upgrades for this property include a full conversion to air-source heat pumps (ASHPs), installation of a small rooftop solar PV system (approximately 11 kW), and enhancements to the building's envelope, which will involve dense-pack wall and attic insulation along with window upgrades. The estimated cost for the HVAC installation is around $170,000. Limited roof space restricts the scale of the solar PV and battery energy storage systems (BESS), but the building is eligible for up to $10,000 per unit through Mass Save whole-home ASHP rebates [54], 0% interest HEAT Loans (up to $25,000)and federal tax credits (30% of the project cost, capped at $2,000 for HVAC and $1,200 for envelope upgrades) [55]. Envelope improvements are also supported through Mass Save, which offers 75% to 100% coverage for air sealing and insulation [47]. With these incentives, the net cost of the HVAC installation is estimated to be reduced to about $30,000. The modest solar PV system is expected to generate around 1,200 to 1,500 kWh per month, which will lead to energy savings and improved thermal comfort at minimal net cost.

624 Hyde Park Ave. (1963, 24 units): This mid-century building has a moderate to high energy use intensity of approximately 138 kBtu/ft² and uses Fuel Oil 1 for heating. Previously partnered with ABCD and served by Eversource, 624 Hyde Park Ave. is a strong candidate for central or in-unit ASHPs, installation of a rooftop solar PV and battery system (approximately 44 kW), and building envelope improvements, including attic insulation, air sealing, and window replacements. The estimated cost for the HVAC upgrades is around $192,000. The building may qualify for per-unit or custom HVAC rebates through Mass Save's multifamily track, as well as full funding for HVAC, insulation, and lighting through the [56] if at least 50% of the tenants qualify as low-income. Pending the rollout of the HEEHRA rebate, it may offer up to $8,000 per unit, as shown in Table 17. Combined with federal tax credits (30% for HVAC, PV, and envelope) [55], the net cost could be significantly reduced. PV production is projected at 4,000 to 6,000 kWh per month, and participation in the ConnectedSolutions program could generate $275 per kW per year for battery dispatch [57]. Even if the building is not eligible for LEAN, the HVAC cost may still be reduced to about $36,000 through other rebates and tax credits. Past success stories, such as the Riley House retrofit [56], illustrate the viability of this approach, where energy savings of 30% and over $100,000 in avoided costs were achieved.

60–66 Brainerd Rd. (2012, 79 units): As a large, modern multifamily property with low energy use intensity of approximately 47 kBtu/ft² and a natural gas-based heating system, 60–66 Brainerd Rd. is targeted for strategic decarbonization. Its efficient envelope requires minimal upgrades, but transitioning to a standard ASHP system is proposed, alongside the installation of a large solar PV and battery energy storage system (114 kW PV and 482 kWh battery storage). The estimated cost for the HVAC upgrades is around $632,000. This property qualifies for Mass Save custom commercial rebates and the 30% federal Investment Tax Credit (ITC) for commercial multifamily HVAC, solar, and battery systems. Performance payments from ConnectedSolutions [53] may exceed $1,400 annually, and the PV array will generate revenue through the SMART solar tariff [26]. Additionally, implementing these upgrades now supports compliance with BERDO emissions regulations [11], potentially avoiding future carbon penalties. The battery storage component alone has a projected

Task 7: Economic & ROI Analysis: *Tariq Anwar & Pat Connell*

This section presents a detailed financial analysis of the proposed deep energy retrofits for the three multifamily buildings under study: 24 Mt. Vernon Street, 624 Hyde Park Avenue, and 60–66 Brainerd Road. Building upon the technical assessments and scenario modeling outlined in previous sections, we provide a comprehensive breakdown of total upgrade costs, applicable incentives, and projected net investments for each property. These evaluations consider factors such as building age, construction type, existing energy systems, and eligibility for various incentive programs. By integrating available rebates, tax credits, and financing options, this analysis aims to offer a clear understanding of the financial implications and benefits associated with the recommended retrofits.

24 Mt. Vernon St. (20 units, constructed in 1920): This building, which was built before 1950, has high energy consumption and uses costly fuel oil 2 for heating. The planned deep retrofit involves changing the oil-fired heating system to air-source heat pumps (ASHPs), installing a modest 11 kW solar PV array, incorporating a small battery for backup, and enhancing the building's envelope with dense-pack insulation and new windows. Key details for this retrofit are: Estimated Total Upgrade Cost: Approximately $240,000, which covers the new HVAC system $170,000 for heat pumps and distribution, an 11 kW PV system $30,000, as seen in Table 19, and improvements to the envelope insulation and windows about $50,000. The limited roof space restricts the size of the PV array and battery. Net Cost After Incentives: Approximately $13,000 (in the best-case scenario).

Generous incentives come close to fully covering the project's expenses. Mass Save provides up to $10,000 per unit for whole-home heat pump installations, which could cover most of the HVAC costs for the 20 units. Additionally, there is a 30% federal tax credit (limited to $2,000 for heat pumps and $1,200 for the envelope per unit). Mass Save also funds 75–100% of insulation and air sealing expenses. With these incentives, the owner's out-of-pocket expenses are reduced to the lower tens of thousands. (Table 3 indicated a range of about $13,000–$36,000 net for this property.) Projected Annual Energy Cost Savings: Estimated to be around $20,000–$25,000 each year. Most of these savings come from the elimination of fuel oil for heating and enhanced efficiency. The previous heating bills for oil were significant No.2 oil priced at roughly $4 per gallon in MA [58]; switching to efficient heat pumps reduces heating energy consumption by approximately 60–70%. The added insulation and air sealing are anticipated to lower overall heat loss by about 30%, thereby reducing heating requirements. Moreover, the 11-kW solar array is expected to produce approximately 14–18 MWh annually, which would offset about $3,000–$4,000 in electricity costs each year (improving the building's electricity bill and supplying power for the new heat pumps). Overall, the retrofit is projected to decrease annual energy use by approximately 30% or more, resulting in significant savings. Simple Payback Period: Approximately 0.5–1.5 years (less than 2 years). The substantial incentives result in a very quick payback period. In the best-case scenario (where the net cost is around $13,000 versus savings of around $25,000 per year), the upgrade pays itself off in under one year. Even under more conservative assumptions (net cost of about $30,000), the payback period is estimated to be 1 to 2 years – an exceptionally short duration for a deep retrofit. This indicates that the upgrades at Mount Vernon are highly cost-effective, effectively recouping the investment almost immediately through savings on energy and rebates.

624 Hyde Park Ave. (24 units, built in 1963): This 1960s building has a moderately high energy consumption level and currently uses fuel oil 1 for heating. The proposed retrofit plan includes transitioning to efficient ASHP heating and cooling, installing a larger approximately 44 kW solar PV array along with a battery, and enhancing the building's envelope through attic insulation, air sealing, and window replacements. Key financial information: The total estimated upgrade cost is around $450,000, including approximately $192,000 for the HVAC system, roughly $130,000 for a 44 kW solar PV system, an estimated $100,000 for a battery storage system, and around $60,000 for insulation and window upgrades. However, the net cost after incentives could be as low as $15,000. Since this property may qualify as affordable housing, it can access additional programs such as Mass Save's multifamily initiative and federal tax credits, which can significantly reduce the total cost. Importantly, if more than 50% of tenants meet income eligibility, the project may qualify for the LEAN Multifamily program, which could fully finance HVAC, insulation, and even lighting improvements. In the ideal scenario, most major costs would be covered by utility and community programs. Additionally, the pending federal HEEHRA rebate could provide up to $8,000 per unit for heat pumps, potentially adding around $204,000 if approved. When combined with the 30% Investment Tax Credit for solar and battery systems, the owner's net cost may fall into the lower tens of thousands. The estimated annual energy cost savings are approximated to be between $30,000–$40,000 per year. By discontinuing fuel oil use, the building avoids a significant annual expense for heating fuel. Although heating will shift to electric, the substantial savings will result in significant cost reductions.

60–66 Brainerd Rd. (79 units, built in 2012): This large, modern multifamily property uses natural gas for heating and has the lowest energy intensity of the three buildings. To meet BERDO targets and fully electrify, the retrofit plan involves replacing the gas heating with high-efficiency air-source heat pumps, installing a large solar PV array, integrating battery storage for load flexibility and backup, and deploying advanced controls. Envelope upgrades were deemed unnecessary due to the building's newer construction.

The estimated total upgrade cost is approximately $1,133,000. This includes $671,500 for 79 units of ASHPs, $410,000 for the PV and battery system, and $51,500 for controls and monitoring. These investments aim to electrify heating/cooling, improve demand response, and reduce grid reliance. The net cost after incentives is estimated at $600,000-$650,000. The project benefits from a 30% federal tax credit on eligible HVAC, solar, and battery components. Mass Save incentives are expected to partially cover HVAC or control costs. Enrollment in ConnectedSolutions could generate $7,000-$10,000 annually in demand response revenue. The building may also qualify for the SMART solar tariff's long-term production-based incentives.

The estimated annual energy cost savings range from $40,000 to $50,000 per year. These savings come from reduced gas use, solar offsetting electric loads, and battery grid services revenue. Despite the higher upfront cost, this retrofit has a strong long-term return by leveraging scale, advanced controls, and solar-battery synergy. The simple payback period is estimated at 12-16 years, with potential for faster returns if electricity rates rise or additional incentives are secured. This demonstrates how large multifamily buildings can achieve deep decarbonization through integrated electrification and distributed energy.

Several scenarios were assessed for each building comparing the overall lifespan CO_2e reduction, net present value (NPV), and internal rate of return (IRR) of each scenario. The control scenario for each building assumes:

- Using the maximum available roof space for solar PV;
- Having 4.25 hr of battery storage (after ECM implementation);
- Air-source heat pump with 3.9 coefficient of performance;
- 4%, 15-year loan;
- HEAT loan up to $25k for heat pump;
- 5% saved on energy consumption from envelope, insulation, and appliance ECMs.

Consistent assumptions held through modeling were:

- 0.5% annual reduction in PV performance,
- 3% annual reduction in BESS and ASHP performance,
- PV inverter and ASHP replacement at year 13 of the system
- 2% annual inflation rate for energy costs
- 90% of BESS depleted during ConnectedSolutions "Active Demand" periods
- 100% electrification of heating/cooling when implementing ASHP
- On-site back-up generator purchase/use in instances with no BESS.

Graphical results of modeling these scenarios can be seen in Figure 7, Figure 8, Figure 9, and Figure 10. Figure 7 compares NPV and CO2e reduction across varying PV array and BESS sizes. Figure 8 compares NPV and CO2e reduction across varying ECMs implemented. Figure 9 compares NPV and CO2e reduction across varying ASHP efficiencies. Figure 10 compares NPV and CO2e reduction across varying loan interest rates.

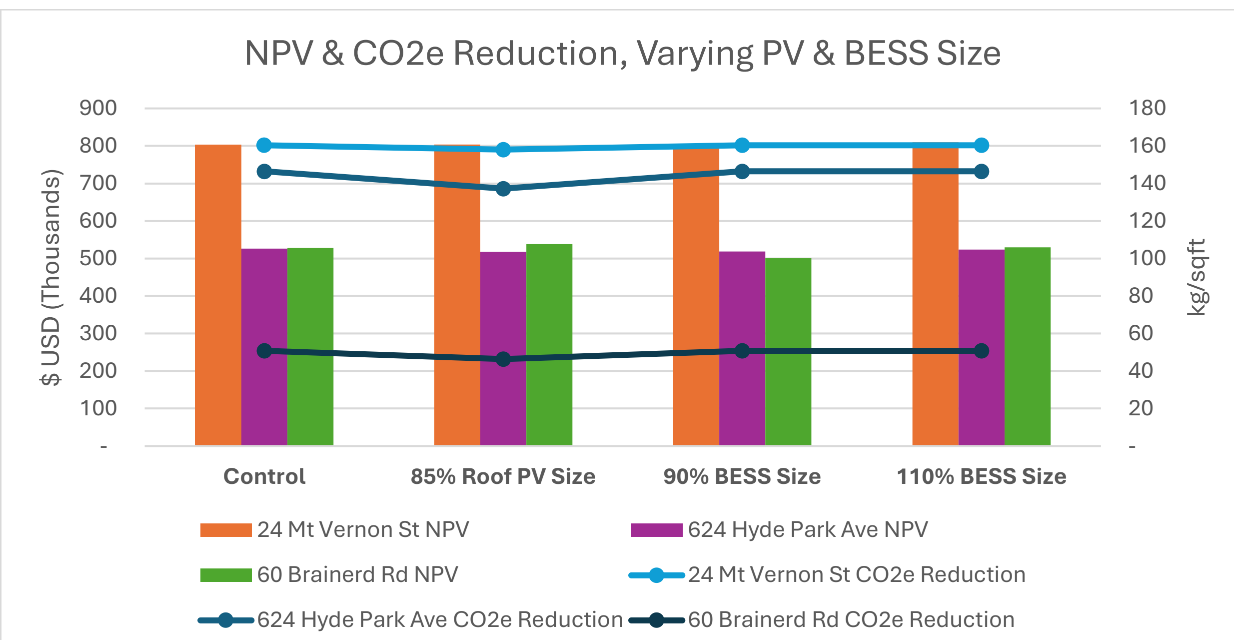


Figure 7: *Net Present Value & CO2e Reduction for Varying PV & BESS Sizes*

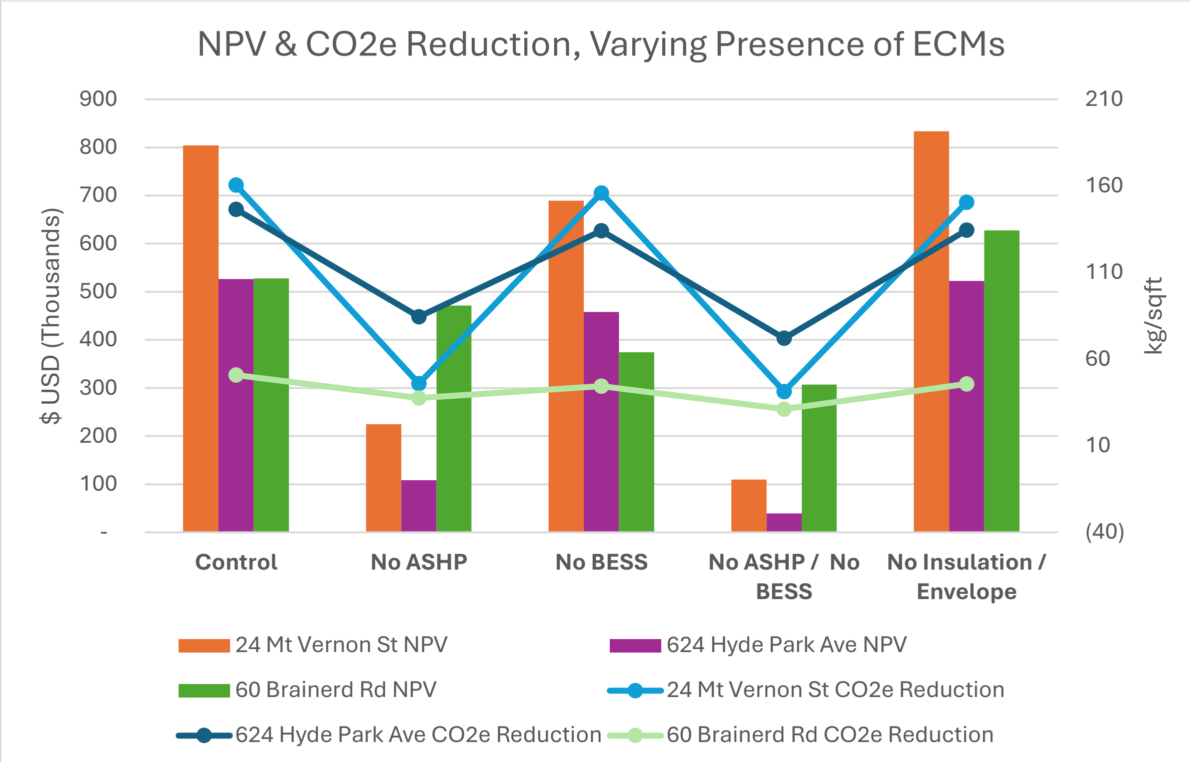


Figure 8: *Net Present Value & CO2e Reduction for Varying Presence of Energy Conservation Measures*

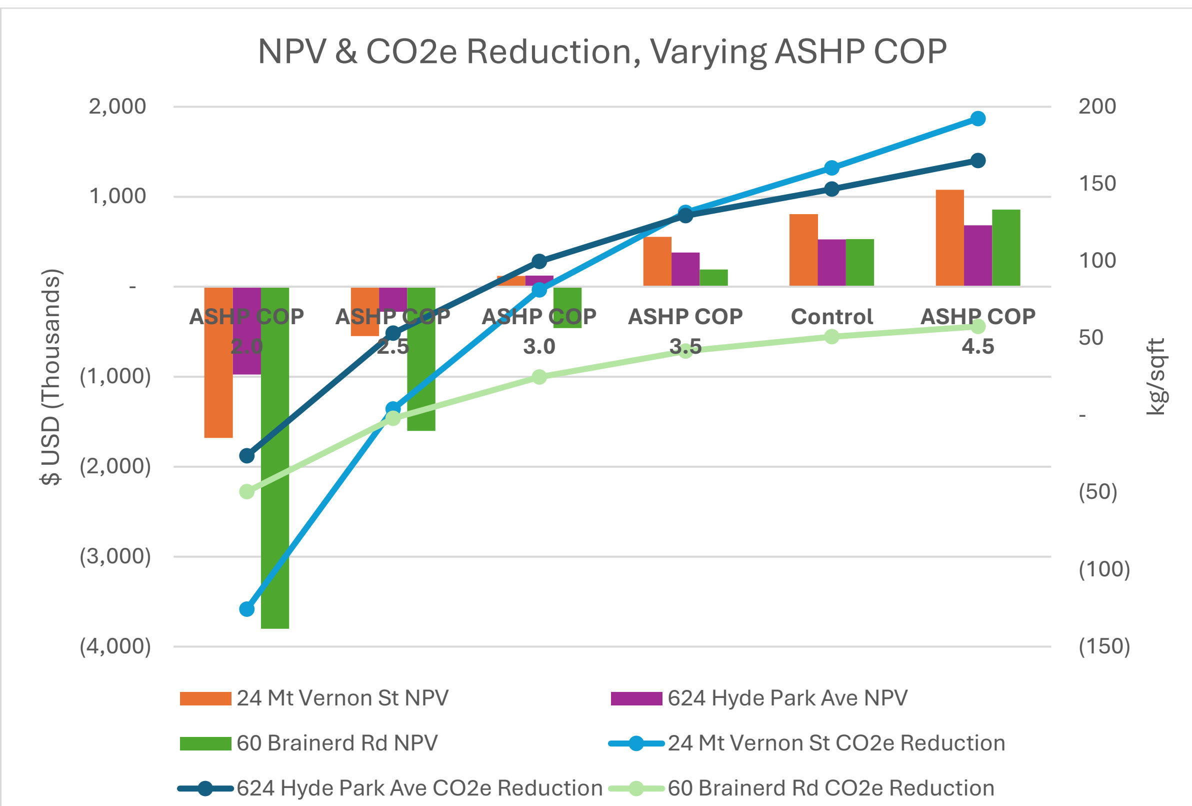


Figure 9: *Net Present Value & CO2e Reduction for Varying ASHP COP*

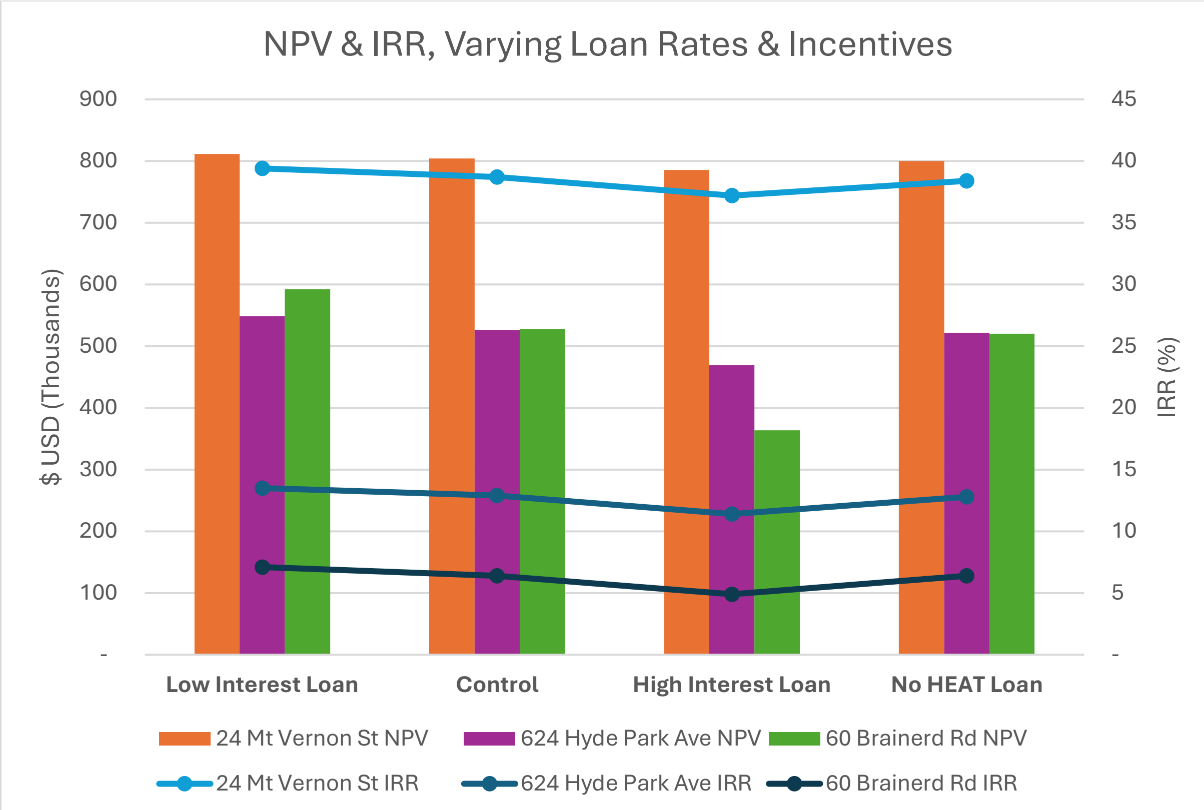


Figure 10: *Net Present Value & CO2e Reduction for Varying Loan Rates and Incentive Loans*

As shown in Figure 7, PV array size didn't affect NPV significantly when including the other ECMs, but it did lessen CO2 reduction, as well as hours of resilience due to a lower capacity to replenish energy consumed from the BESS. BESS size had a direct correlation to NPV but didn't affect emissions, as it's used for energy storage and not production. A larger BESS size would improve resilience, too.

From Figure 8, the loss of a BESS shows a loss in CO2 mitigation due to back-up power needing to be secured by fossil fuel burning generators. The improvement of NPV from no insulation improvements is due to the low assumption of 5% energy conservation used on top of other ECMs that would require a fair investment to implement. A more liberal estimate of 25-30% energy savings from insulation would show both greater NPV and emissions reductions.

Figure 9 shows the importance of an efficient heat pump for electric heating and cooling. Below a COP of 3.0, all three buildings had NPVs in the negative. At COP of 2.0, total building emissions were also increased compared to no microgrid system implemented. This low efficiency is why the minimum EER for A/C systems sold in the northern US needs to be above 11.7, which translates to a COP of 3.4 [59]. The curve does show a taper effect on both NPV and emissions as COP increases.

Figure 10 is meant to show how interest rates will affect the IRR and NPV of each microgrid system. The low interest rate is 2.5% APY while the high rate selected is 7.5%. These rates show that the lower that the overall NPV and IRR of the project are, the greater that the loan's interest rate will be. The HEAT loan is most impactful to Brainerd because it requires the largest heat pumps and thus will be able to make the most of the loan.

Tabulated data for each of these scenarios and the modelling rationale based on retrieved data throughout this study can be found in Appendix E.

Conclusions

From this report, an encompassing model was developed incorporating the totality of rebate, incentive, and penalty programs; localized data on temperature, irradiance, and energy costs; data on residential building floor area, unit count, electrical consumption, heating fuel consumption, and emissions; and cost models for capital equipment utilizing their anticipated operating expenses and emission reductions.

As a result of this modeling, we have demonstrated not only feasibility in implementing a microgrid system with various methods of attaining sustainable resiliency but the overwhelming positive implications for both finances as well as GHG emission reductions. Each individual piece of sustainable resilience—solar PV, BESS, ASHP, insulation & energy efficiency improvements—has been shown to independently be a net positive for resilience, sustainability, and investment; incorporating the ECMs and independent power generation methods all together would yield the greatest results all three of the goals.

As shown in Table 24, every scenario (except those utilizing ASHPs with a COP below the minimum of 3.4 to be sold in the northern US) had an IRR above 3.0% [59]. In the case of a building owner considering implementing some or all of these measures, the savings on energy expenses could be tied into the overall rent for their tenants. They may even consider implementing a premium from advertising that they have energy independence and energy security in their building—with it being sustainable as well!

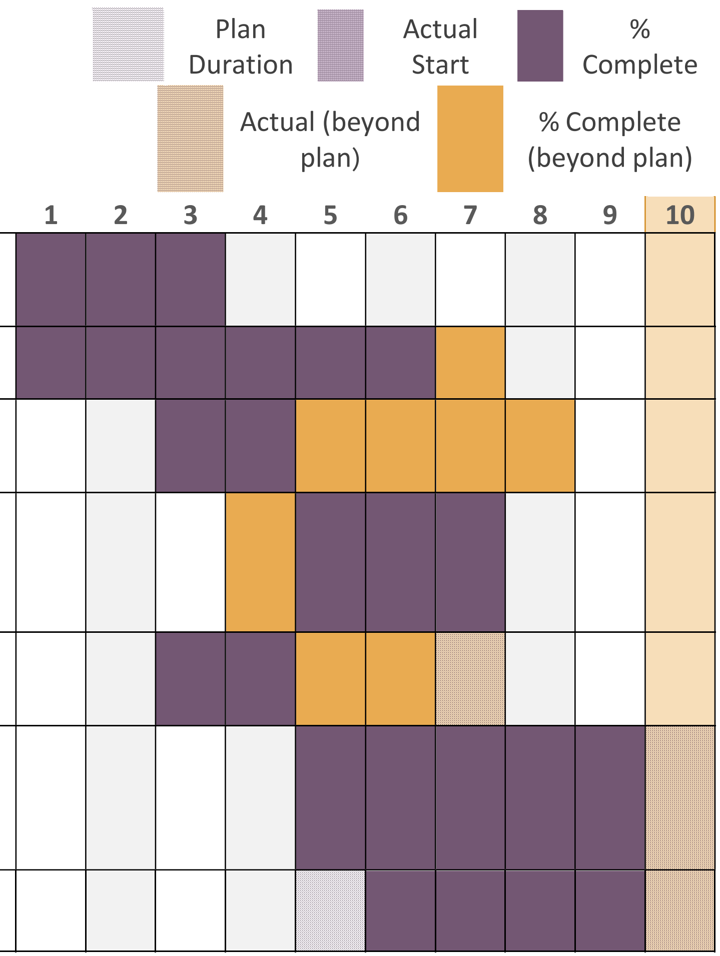
Overall, this project showed how a sustainable microgrid system would be for multi-unit residential buildings in Boston is obviously a positive investment. As both Boston and Massachusetts seek to neutralize their carbon footprint by 2050, actually implementing sustainable initiatives will be necessary to achieve that goal, and we believe we have performed a strong, thorough, convincing analysis as to why building owners should do their part.

The next steps would then just to be reaching out to those owners to present to them our study. From there, we could analyze their buildings using their data and our model, hopefully establishing ourselves as a reputable Engineering Procurement Construction company in the process.

Up-to-Date Gantt Chart

Feasibility of Resiliency & Sustainability in Residential Multi-Unit Buildings in Boston

	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1	Selection of Multi-unit Residential Buildings	1	3	1	3	100%
2	Data Collection & Energy Use Analysis	1	6	1	7	100%
3	Energy Conservation Measures	3	2	3	6	100%
4	Microgrid Systems & Renewable Energy Integration Feasibility	5	3	4	4	100%
5	Policy & Regulatory Framework Analysis	3	2	3	5	100%
6	Financial Incentives & Strategic Outlook for Upgrade Implementation	5	5	5	6	85%
7	Economic & ROI Analysis	5	5	6	5	80%



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Appendices

Appendix A: Energy Demand Profile – *Pat Connell*

Table 10 shows the mean daily solar irradiance in Boston and the on-site energy generated at each respective building being investigated in this study. These estimates were generated through the National Renewable Energy Laboratories' PVWatts Calculator [16]. System sizes were estimated using PVWatts as well by mapping out the available area for PV on each roof. By taking the number of days in each month and multiplying them by the system size and solar irradiance, the monthly energy generated was calculated. Summing the energy generated each month together presented the annual PV energy generation total for each site.

Table 10: *Mean Peak Solar Hours in Boston MA and On-Site PV System Energy Generation*

Month	Solar Radiation (kWh / m2 / day)	AC Energy (kWh)		
		24 Mt. Vernon (10.9 kW DC)	624 Hyde Park (44.1 kW DC)	60 Brainerd (114.3 kW DC)
Jan	3.53	1,001	4,019	9,645
Feb	4.23	1,072	4,325	11,159
Mar	5.34	1,456	5,735	14,618
Apr	5.41	1,361	5,493	14,269
May	5.28	1,335	5,851	13,695
Jun	5.83	1,395	5,581	14,246
Jul	6.15	1,508	6,063	15,498
Aug	5.80	1,422	5,721	14,669
Sep	5.26	1,281	5,590	14,209
Oct	4.33	1,140	4,360	11,247
Nov	3.15	844	3,472	8,841
Dec	2.54	718	3,280	8,576
Annual Total		**14,533**	**59,490**	**150,672**

Table 11 presents the heating (HDD) and cooling degree days (CDD) in Boston throughout the years 2022, 2023, and 2024 [60]. Degree days are daily temperature differentials to a reference temperature; here that temperature is 65°F. For every °F the day's difference in average temperature relative to the reference temperature is, a degree day is counted. When the temperature is above 65°F, it is a CDD (energy is used to provide cooling). When the temperature is below 65°F, it is an HDD (energy is used to provide heating). The numbers for each month represent the summation of HDDs and CDDs in that respective month.

Table 11: *Heating and Cooling Degree Days by Month for Boston MA, 2022-2024 [60]*

	Heating Degree Days (°F)			Cooling Degree Days (°F)		
Month	**2022**	**2023**	**2024**	**2022**	**2023**	**2024**
Jan	1255	913	1071	0	0	0
Feb	942	897	922	0	0	0
Mar	780	812	753	0	0	0
Apr	501	439	527	0	9	0
May	202	225	222	60	22	37
Jun	44	99	13	95	97	141
Jul	0	0	0	352	294	319
Aug	0	1	11	329	148	197
Sep	99	98	59	48	119	63
Oct	314	251	303	0	26	6
Nov	556	737	570	5	0	5
Dec	941	808	989	0	0	0
Total	**5634**	**5280**	**5440**	**889**	**715**	**768**

By taking the HDDs and CDDs for each year and comparing them to the heating fuel and electricity consumption across the years, a linearization model can be made by finding the least squares regression of each building's heating and cooling consumption rates. Knowing that each building is heated by fossil fuels and cooled by electricity (either with central air or in-window A/C units), it can be assumed that fuel-based emissions are dependent on HDDs while electricity-based emissions are dependent on CDDs. Equation 1 and Equation 2 show the model that can be generated from the least squares regression for heating and cooling:

$$kCO_2e_{fuel} = f \times D + h \times HDD \qquad \text{Equation 1}$$

$$kCO_2e_{elec.} = e \times D + c \times CDD \qquad \text{Equation 2}$$

where *HDD* is heating degree days, *CDD* is cooling degree days, *f* is a coefficient for baseline heating emissions per day, *e* is a coefficient for baseline cooling emissions per day, *h* is a coefficient for emissions per HDD, *c* is a coefficient for emissions per CDD, and *D* is days.

Results for month-by-month emissions estimates—based on BERDO-reported emissions and Boston temperature data—for each building can be found in Table 12 [14, 60]. Ranges are based on variance of HDD and CDD data utilized in the model [60]. Visualization for the emissions model estimates of each building can be found in Figure 11.

Table 12: *Temperature-Dependent Emissions Profile of Studied Buildings*

	24 Mt. Vernon		624 Hyde Park		60 Brainerd	
Month	Heating kgCO2e/unit	Cooling kgCO2e/unit	Heating kgCO2e/unit	Cooling kgCO2e/unit	Heating kgCO2e/unit	Cooling kgCO2e/unit
Jan	466 – 642	-	665 – 915	-	218 – 300	-
Feb	461 – 484	-	657 – 690	-	215 – 226	-
Mar	386 – 416	-	550 – 594	-	180 – 195	-
Apr	228 – 274	0 – 16	325 – 391	0 – 13	106 – 128	0 – 13
May	105 – 117	40 – 114	149 – 167	33 – 95	49 – 55	33 – 96
Jun	4 – 49	165 – 266	6 – 70	138 – 222	2 – 23	139 – 224
Jul	-	568 – 681	-	474 – 568	-	477 – 572
Aug	0 – 5	254 – 618	0 – 7	212 – 515	0 – 2	214 – 519
Sep	32 – 56	76 – 221	46 – 79	64 – 185	15 – 26	64 – 186
Oct	131 – 166	0 – 47	187 – 236	0 – 39	61 – 77	0 – 40
Nov	267 – 370	1 – 12	381 – 528	1 – 10	125 – 173	1 – 10
Dec	420 – 517	-	599 - 736	-	196 – 241	-

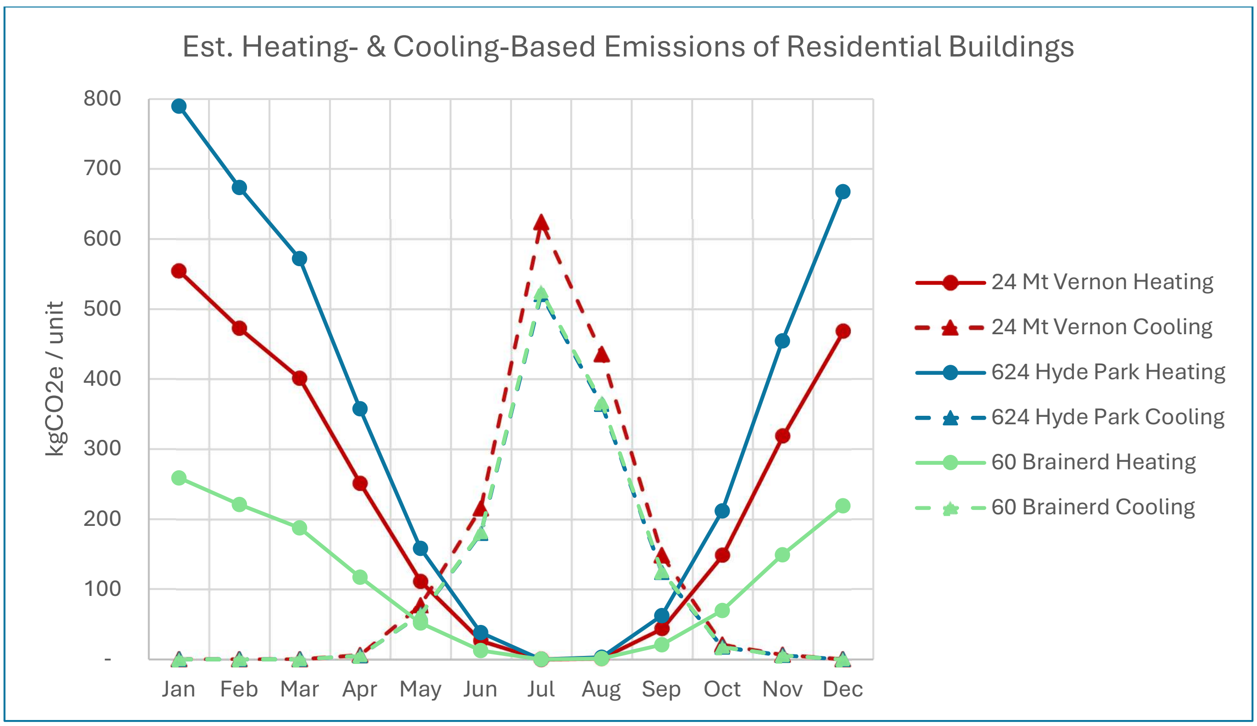

Figure 11: *Emissions Output Estimates per Unit for Selected Buildings*

Appendix B: Energy Conservation Outlooks – *Pat Connell*

Table 13 represents funding through Mass Save from both gas and electric utilities in the Boston area *[61]*. Mass Save offers a lot of building envelope and efficiency opportunities. We have tabulated this data to be able to estimate how much subsidization the improvements for buildings we're looking at can garner, as well as seeing how much they may be able to reduce energy use.

Table 13: *Mass Save Energy Efficiency Improvement Expenses and Savings - 2023*

Fuel	Reporting Period	Program	Initiative	Participants	Expenditures ($)		Annual Electric Savings (MWh) / (kWh)		Annual Gas Savings (Therms)	
					Total	Per Participant	Total	Per Participant	Total	Per Participant
Electric	Actual	Residential New Buildings	New Homes & Renovations	5,496	$ 17,072,132	$ 3,106	9,151	1,665	247	0.045
Electric	Actual	Residential Existing Buildings	Coordinated Delivery	48,464	$ 86,395,226	$ 1,783	18,370	379	11,466	0.237
Electric	Actual	Residential Existing Buildings	Retail	78,483	$ 119,263,770	$ 1,520	24,368	310	(641)	(0.008)
Electric	Planned	Residential New Buildings	New Homes & Renovations	12,352	$ 22,627,296	$ 1,832	2,544	206	-	0.000
Electric	Planned	Residential Existing Buildings	Coordinated Delivery	58,116	$ 106,716,356	$ 1,836	15,205	262	1,081	0.019
Electric	Planned	Residential Existing Buildings	Retail	150,436	$ 98,069,398	$ 652	(6,048)	(40)	(7,153)	(0.048)
Gas	Actual	Residential New Buildings	New Homes & Renovations	2,959	$ 10,088,766	$ 3,410	120	40	892,063	301.47
Gas	Actual	Residential Existing Buildings	Coordinated Delivery	26,063	$ 85,019,003	$ 3,262	2,306	88	3,567,862	136.89
Gas	Actual	Residential Existing Buildings	Retail	27,926	$ 79,485,254	$ 2,846	(44,649)	(1,599)	5,280,130	189.08
Gas	Planned	Residential New Buildings	New Homes & Renovations	4,133	$ 8,384,683	$ 2,029	184	44	664,391	160.75
Gas	Planned	Residential Existing Buildings	Coordinated Delivery	55,873	$ 98,043,106	$ 1,755	2,471	44	3,582,104	64.11
Gas	Planned	Residential Existing Buildings	Retail	37,304	$ 39,894,118	$ 1,069	(3,911)	(105)	2,781,956	74.58

Table 14 shows the monthly prices for various forms of energy in the Boston area from the past few years *[62] [63] [58] [64] [65]*. This data set was used for the basis of extrapolating energy costs and savings for future planning.

Table 14: *Home Energy Prices in Boston-area, 2020-2024*

Month	**Natural Gas Price Boston by Year (USD/therm)** [62]					**Electricity Price in Boston by Year (USD/kWh)** [63]				
	2020	**2021**	**2022**	**2023**	**2024**	**2020**	**2021**	**2022**	**2023**	**2024**
Jan	1.464	1.553	1.805	2.317	2.074	0.232	0.230	0.266	0.391	0.297
Feb	1.459	1.494	1.891	2.341	2.176	0.230	0.230	0.269	0.386	0.291
Mar	1.471	1.544	1.958	2.193	2.169	0.231	0.234	0.267	0.389	0.297
Apr	1.498	1.564	2.217	2.143	2.308	0.231	0.238	0.268	0.341	0.297
May	1.400	1.580	2.122	2.019	2.162	0.220	0.227	0.257	0.328	0.297
Jun	1.365	1.528	2.206	1.833	1.958	0.219	0.229	0.260	0.322	0.297
Jul	1.578	1.693	2.475	1.902	2.201	0.213	0.225	0.270	0.291	0.301
Aug	1.621	1.841	2.524	2.026	2.184	0.209	0.228	0.288	0.279	0.305
Sep	1.552	1.757	2.416	1.927	2.092	0.209	0.228	0.289	0.279	0.302
Oct	1.324	1.714	2.125	1.656	1.659	0.209	0.228	0.291	0.282	0.302
Nov	1.337	1.752	2.158	1.723	2.024	0.217	0.244	0.358	0.286	0.306
Dec	1.589	1.761	2.263	2.232	2.510	0.217	0.245	0.358	0.285	0.305
Month	**Heating Oil Price in Boston by Year (USD/gal)** [58]					**Kerosene Price in Boston by Year (USD/gal)** [64] [65]				
	2020	**2021**	**2022**	**2023**	**2024**	**2020**	**2021**	**2022**	**2023**	**2024**
Jan	3.014	2.505	3.586	4.656	4.030	3.843	3.897	4.188	4.457	4.595
Feb	2.844	2.706	3.983	4.379	4.185	4.089	4.158	4.485	4.756	4.906
Mar	2.560	2.873	5.058	4.177	4.103	4.084	4.191	4.549	4.776	4.942
Apr					4.050	3.994	4.160	4.504	4.726	4.885
May					3.856	4.737	4.974	5.401	5.619	5.803
Jun					3.702	3.503	3.692	4.026	4.146	4.269
Jul					3.735	3.457	3.644	3.964	4.091	4.205
Aug					3.561	3.411	3.595	3.901	4.035	4.141
Sep					3.458	3.366	3.547	3.838	3.980	4.077
Oct	2.077	3.243	5.445	4.250	3.493	3.951	4.197	4.522	4.669	4.790
Nov	2.138	3.347	5.540	4.159	3.485	3.880	4.145	4.439	4.579	4.705
Dec	2.342	3.316	4.666	4.077	3.578	3.867	4.140	4.407	4.554	4.686

Appendix C: Energy Resiliency Strategies – *Pat Connell*

Table 15 below shows the investigation performed on the viability of utilizing wind energy as a sustainable resilience strategy. Equation 3 shows the formula dictating the power in wind. According to Equation 3, the power generated by a wind-facing horizontal axis wind turbine (HAWT) would increase exponentially with the increase in radius. Vertical axis wind turbines (VAWT) would only increase their power output linearly with an increase in radius, as the wind-swept area is the diameter multiplied by the height.

Table 15: *Financial Payback Period Analysis for a 50 kW Sky Farm [33] VAWT with estimated cost up to $8000 w.r.t 3 Federal Incentive in Boston*

Name plate Capacity	Est. Cost (USD)	Wind Speed (m/s)	Coeff. of Power (Cp)	Rotor Diameter (m)	Rotor Height (m)	Wind Sweep Area (m^2)	Power Produced (kW) By Avg. Wind Speed	Energy Produced Annually (Kwh)	Annual Savings ($)	Net Annual Savings ($)	Payback Period (yrs)	Payback w/ IRA 30% (yrs)
50 KW	$8,000	4	35%	5	6	30	0.412	3606	$ 829	$ 529	15.1	10.6
		4.5	35%	5	6	30	0.586	5134	$ 1,181	$ 881	9.1	6.4
		5	35%	5	6	30	0.804	7042	$ 1,620	$ 1,320	6.1	4.2
		5.5	35%	5	6	30	1.070	9373	$ 2,156	$ 1,856	4.3	3.0

$$P_w = \frac{\rho}{2} A V^3 \qquad \text{Equation 3}$$

where P_w is the power in the wind, A is the cross-sectional area, V is the velocity of the wind, and ρ is the density of the air.

Figure 12 shows an overview of the variable inputs, ECMs, power generation methods, financial modifiers, and outputs of the microgrid systems being proposed relate to one another. The map is intended to flow from left to right, showing how the input variables affect ECMs and power generation, which affect financial modifiers, and those affect the outputs on resilience, sustainability, and finance.

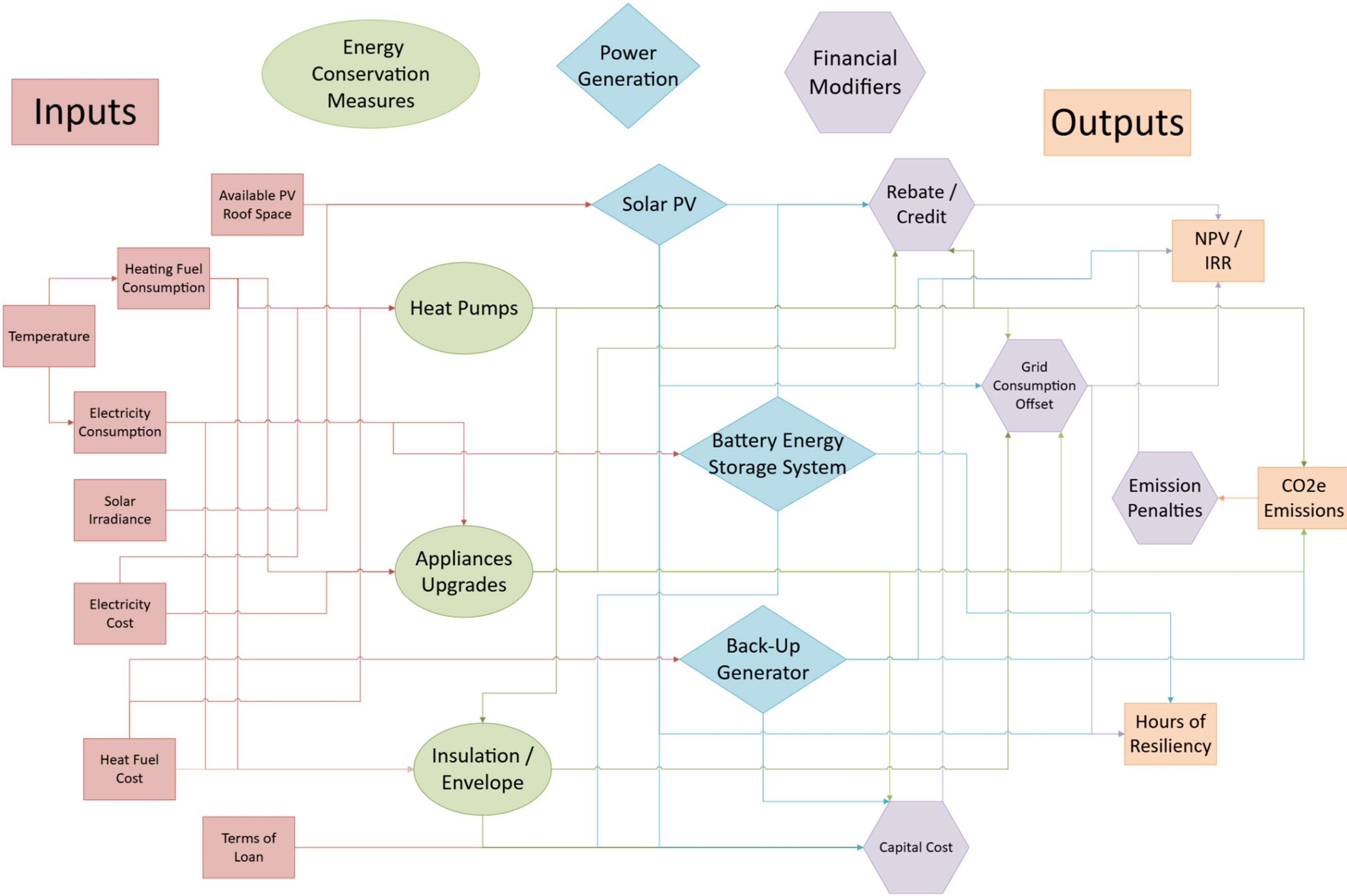

Figure 12: *Map displaying variables and results for assessing feasibility of resilience & sustainability in multi-unit residential buildings*

When investigating the logistics of a diesel generator, the costs, GHG emissions, and power potential were all needed to provide the best assessment for what the renewable strategies would compete against. Table 3 provides data on costs, energy potential, and emissions of various fuel sources a generator's engine would use *[35, 66, 67, 68]*.

Table 16: *Diesel Costs, Emissions, and Power Potential*

Fuel Make-up	Cost ($/gal)	Energy Content (MJ/gal)	CO2 Emissions (kg/gal)	NOx Emissions (kg/gal)	CO2e Emissions (kg/gal)
100% Diesel	3.64	144.77	2.72	0.0535	16.9
20% Biodiesel	3.53	142.78	2.67	0.0535	16.8
100% Biodiesel	4.04	134.84	2.47	0.0535	16.6
DBE10	3.45	137.22	2.58	0.0419	13.7
DBE20	3.44	131.65	2.45	0.0381	12.5
DBE30	3.43	126.08	2.33	0.0358	11.8
DBE40	3.42	120.51	2.21	0.0339	11.2
DBE50	3.41	114.94	2.08	0.0262	9.0

For estimating the emissions for powering each building via diesel generator, Equation 4 provides a mass rate of CO2 emissions:

$$\dot{m}_{CO2} = \frac{C_f}{h_f}\frac{M_C}{M_{CO2}}P \qquad \text{Equation 4}$$

where $\dot{m}_{CO2}$ is the emission rate of CO2 (kg/h), C_f is the carbon content of the fuel (kg_C/gal_{fuel}), h_f is the energy content of the fuel (kWh/gal_{fuel}), M_C is the molecular weight of carbon (kg/kmol), M_{CO2} is the molecular weight of carbon dioxide (kg/kmol), and P is the power demand of the building.

Appendix D: Financial Incentives – *Pat Connell & Tariq Anwar*

Table 17 outlines a variety of potential system upgrades, and refers to programs that may offer tax credits, rebates, and/or subsidization towards the improvements. Table 18 outlines the financial incentives for heat pumps in Massachusetts currently.

Table 17: *Cost-Reduction Incentives for Energy Efficiency Upgrades*

System Upgrade	Incentive Cost Reductions				
	IRA Tax Credit [69]	Energy Star [70]	SMART [26]	Connected Solutions [53]	Mass Save [55]
PV	30%	N/A	15%, up to $1,000 TCR Based Income	N/A	N/A
BESS	30%	N/A	Adder, based on size and power	$1.53 - 275 per kWh	N/A
Electric Paneling	N/A	30%, up to $600	N/A	N/A	N/A
Heat Pump	30%	N/A	N/A	N/A	N/A
Refrigerator	N/A	$25 - 100 for recycle	N/A	N/A	N/A
Stove	Up to $840	N/A	N/A	N/A	$500 (if induction)
Water Heating	N/A	30%, up to $2,000	N/A	N/A	$750/unit, $1,500/system
Smart Controllers	N/A	$100 / thermostat	N/A	$50 enrollment incentive, $20 annual incentive	N/A
Building Envelope	N/A	$600 for windows, $250 for doors	N/A	N/A	30% up to $1,200
Lighting	N/A	N/A	N/A	N/A	Up to $15 per tube LED

Table 18: *Outlining the current heat pump rebates and incentives available in Massachusetts.*

Rebates/Incentives	Amount	Eligibility	Additional info
Mass Save Whole-Home Heat Pump Rebate	\$3,000 per ton, up to \$10,000 per home	Full replacement of the existing heating system with a heat pump must be the primary heating source	Requires a home energy assessment; available through Mass Save participating contractors
Mass Save Partial-Home Heat Pump Rebate	\$1,250 per ton, up to \$10,000	Partial replacement; heat pump supplements existing system	Requires integrated controls to manage dual systems; available through Mass Save participating contractors
Federal Energy Efficient Home Improvement Credit (Section 25C)	30% of project cost, up to \$2,000 annually	Installation of qualified energy-efficient heat pumps in primary residences	Applies to improvements made from Jan 1, 2023, through Dec 31, 2032; must meet specific efficiency standards
High-Efficiency Electric Home Rebate Act (HEEHRA)	Up to \$8,000 for heat pump installation	Households with income ≤150% of area median income	Program rollout pending in Massachusetts; designed to assist low- to moderate-income households with electrification
Mass Save HEAT Loan Program	0% interest financing up to \$25,000	Financing for qualifying energy-efficient home upgrades, including heat pumps	Loan terms vary; requires participation in Mass Save programs

Appendix E: Financial Cashflow & Emissions Models – *Pat Connell*

The tables in Appendix E represent modeled estimates for various energy generation and efficiency scenarios at the buildings considered in this study. Each column has particular calculations dedicated to them. The tables and their respective scenarios are as follows:

- **Table 19:** 24 Mt Vernon St Financing – 10.9 kW PV, 24.6 kWh BESS, 3.9 COP ASHP
- **Table 20:** 624 Hyde Park Ave Financing – 44.1 kW PV, 77.6 kWh BESS, 3.9 COP ASHP
- **Table 21:** 60 Brainerd Rd Financing – 114.3 kW PV, 192.7 kWh BESS, 3.9 COP ASHP

The column titled 'Year' gives the year of the system's installation, with the assumption of '1' being 2025. The column 'Annual Energy Efficiency Savings' quantifies the energy cost savings from implementing measures such as insulation, envelope improvements, and heat pump installation. The column 'Annual Energy Savings from Solar PV' quantifies the energy cost savings from generating electricity through the PV system.

'T&D Demand Savings' provides an estimate on reduced peak grid demand (lessening strain on transmission and distribution) that the energy system offers. Consistently high monthly demand will cost customers more on a $/kW basis.

'BERDO Savings' is a measure of how much energy efficiency and generation will offset non-compliant emission levels per BERDO [11]. The emission limits grow stricter through 2050, leading to higher expenses over time if emissions are not curbed.

'ConnectedSolutions Active Demand Revenue' estimates earnings from the Connected Solutions program, where $275 is earned for each kW sold to the power grid on average across the summer during peak demand periods [71].

'ICAP Savings' concerns the integration of the demand system with ISO New England (ISO-NE). Customers who have chosen third-party supply rates are subject to these 'installed capacity' fees, but they can potentially reduce those fees [72]. The annual ICAP hour, which sets the fee rate, is determined as the highest power demand hour throughout the year. The expected rates for $/kW-month can be found with ISO-NE [73].

'Clean Peak Standard Certificate Revenue' is about revenue from a Department of Energy Resources program, as part of the Clean Peak Energy Portfolio Standard [74]. The formula for calculating certificates involves seasonal change, resilience, and metered resource performance [75]. Similarly, SMART Revenue PV + BESS' assesses the earnings generated from the SMART Program, based on energy generated, system power, and battery capacity [26].

Expenses are seen in the columns on system maintenance (estimated to be 2% of the initial cost, annually), the curtailment service provider (which would control the system response to grid demand), and debt service is a calculated annuity across a specified loan period with interest (here set at 4%).

Table 19: *24 Mt Vernon St Financing - 10.9 kW PV, 24.6 kWh BESS, ASHP 3.9 COP*

Year	Annual Energy Efficiency Savings	Annual energy savings from solar PV	T&D Demand Savings	BERDO Savings	Connected Solutions "Active Demand" Revenue	ICAP Savings	Clean Peak Standard Certificate Revenue	SMART Revenue PV + BESS	Annual System Maintenance (2% est.)	Curtailment Service Provider charge	Debt Service	Annual Cash Flow	Cumulative Cash Flow	CO2 reduction (tonnes/yr)
										Total investment:		($76,954)	($76,954)	
1	$18,369	$1,236	$7,643	$0	$8,333	$156	$324	$89	($1,542)	($2,597)	($6,587)	$25,423	($51,530)	80.1
2	$18,736	$1,254	$7,796	$0	$8,083	$156	$314	$88	($1,573)	($2,519)	($6,587)	$25,749	($25,782)	79.7
3	$19,111	$1,273	$7,952	$0	$7,840	$156	$305	$88	($1,604)	($2,444)	($6,587)	$26,090	$308	79.3
4	$19,493	$1,292	$8,111	$0	$7,605	$156	$296	$87	($1,636)	($2,370)	($6,587)	$26,447	$26,755	78.9
5	$19,883	$1,311	$8,273	$0	$7,377	$156	$287	$87	($1,669)	($2,299)	($6,587)	$26,819	$53,574	78.5
6	$20,281	$1,331	$8,438	$18,269	$7,156	$156	$278	$86	($1,703)	($2,230)	($6,587)	$45,476	$99,050	78.1
7	$20,686	$1,350	$8,607	$18,178	$6,941	$156	$270	$86	($1,737)	($2,163)	($6,587)	$45,788	$144,838	77.7
8	$21,100	$1,370	$8,779	$18,087	$6,733	$156	$262	$86	($1,771)	($2,098)	($6,587)	$46,117	$190,955	77.3
9	$21,522	$1,391	$8,955	$17,997	$6,531	$156	$254	$85	($1,807)	($2,035)	($6,587)	$46,462	$237,417	76.9
10	$21,953	$1,412	$9,134	$17,907	$6,335	$156	$246	$85	($1,843)	($1,974)	($6,587)	$46,823	$284,240	76.5
11	$22,392	$1,433	$9,317	$17,817	$6,145	$156	$239	$84	($1,880)	($1,915)	($6,587)	$47,201	$331,440	76.1
12	$22,839	$1,454	$9,503	$17,728	$5,960	$156	$232	$84	($1,917)	($1,858)	($6,587)	$47,595	$379,035	75.8
13	$23,296	$1,476	$9,693	$17,639	$5,782	$156	$225	$83	($1,956)	($1,802)	($6,587)	$31,341	$410,376	75.4
14	$23,762	$1,498	$9,887	$17,551	$5,608	$156	$218	$83	($1,995)	($1,748)	($6,587)	$48,434	$458,810	75.0
15	$24,237	$1,520	$10,085	$17,463	$5,440	$156	$211	$83	($2,035)	($1,695)	($6,587)	$48,879	$507,689	74.6
16	$24,722	$1,543	$10,286	$17,376	$5,277	$156	$205	$82	($2,075)	($1,645)	$0	$55,928	$563,617	74.3
17	$25,217	$1,566	$10,492	$17,289	$5,118	$156	$199	$82	($2,117)	($1,595)	$0	$56,407	$620,024	73.9
18	$25,721	$1,589	$10,702	$17,203	$4,965	$156	$193	$81	($2,159)	($1,547)	$0	$56,904	$676,927	73.5
19	$26,235	$1,613	$10,916	$17,117	$4,816	$156	$187	$81	($2,202)	($1,501)	$0	$57,418	$734,345	73.1
20	$26,760	$1,637	$11,134	$17,031	$4,671	$156	$182	$81	($2,246)	($1,456)	$0	$57,950	$792,295	72.8
21	$27,295	$1,661	$11,357	$16,946	$4,531	$156	$176	$80	($2,291)	($1,412)	$0	$58,500	$850,794	72.4
22	$27,841	$1,686	$11,584	$16,861	$4,395	$156	$171	$80	($2,337)	($1,370)	$0	$59,068	$909,862	72.1
23	$28,398	$1,711	$11,816	$16,777	$4,264	$156	$166	$79	($2,384)	($1,329)	$0	$59,654	$969,516	71.7
24	$28,966	$1,736	$12,052	$16,693	$4,136	$156	$161	$79	($2,432)	($1,289)	$0	$60,259	$1,029,775	71.3
25	$29,545	$1,762	$12,293	$16,610	$4,012	$156	$156	$79	($2,480)	($1,250)	$0	$60,882	$1,090,657	71.0
Total	**$588,361**	**$37,102**	**$244,804**	**$348,541**	**$148,054**	**$3,912**	**$5,753**	**$2,087**	**($49,392)**	**($46,142)**	**($98,803)**	**IRR 38.74%**	**$1,090,657**	**1885.8**

Table 20: *624 Hyde Park Ave Financing – 44.1 kW PV, 77.6 kWh BESS*

Year	Annual Energy Efficiency Savings	Annual energy savings from solar PV	T&D Demand Savings	BERDO Savings	Connected Solutions "Active Demand" Revenue	ICAP Savings	Clean Peak Standard Certificate Revenue	SMART Revenue PV + BESS	Annual System Maintenance (2% est.)	Curtailment Service Provider charge	Debt Service	Annual Cash Flow	Cumulative Cash Flow	CO_2 reduction (tonnes/yr)
										Total investment:		**($205,241)**	**($205,241)**	
1	$17,714	$6,569	$6,561	$0	$7,504	$493	$1,021	$0	($4,114)	($2,557)	($18,101)	$15,089	($190,152)	74.6
2	$18,068	$6,667	$6,692	$0	$7,278	$493	$990	$0	($4,197)	($2,481)	($18,101)	$15,411	($174,741)	74.3
3	$18,430	$6,766	$6,826	$0	$7,060	$493	$960	$0	($4,280)	($2,406)	($18,101)	$15,748	($158,993)	73.9
4	$18,798	$6,867	$6,962	$0	$6,848	$493	$931	$0	($4,366)	($2,334)	($18,101)	$16,100	($142,893)	73.5
5	$19,174	$6,970	$7,102	$0	$6,643	$493	$904	$0	($4,453)	($2,264)	($18,101)	$16,467	($126,426)	73.2
6	$19,558	$7,073	$7,244	$17,033	$6,444	$493	$876	$0	($4,542)	($2,196)	($18,101)	$33,882	($92,545)	72.8
7	$19,949	$7,179	$7,389	$16,948	$6,250	$493	$850	$0	($4,633)	($2,130)	($18,101)	$34,193	($58,351)	72.4
8	$20,348	$7,286	$7,536	$16,863	$6,063	$493	$825	$0	($4,726)	($2,066)	($18,101)	$34,521	($23,831)	72.1
9	$20,755	$7,394	$7,687	$16,779	$5,881	$493	$800	$0	($4,820)	($2,004)	($18,101)	$34,863	$11,033	71.7
10	$21,170	$7,504	$7,841	$16,695	$5,704	$493	$776	$0	($4,917)	($1,944)	($18,101)	$35,222	$46,254	71.3
11	$21,594	$7,616	$7,998	$16,612	$5,533	$493	$753	$0	($5,015)	($1,886)	($18,101)	$35,596	$81,850	71.0
12	$22,025	$7,730	$8,158	$16,528	$5,367	$493	$730	$0	($5,116)	($1,829)	($18,101)	$35,986	$117,836	70.6
13	$22,466	$7,845	$8,321	$16,446	$5,206	$493	$708	$0	($5,218)	($1,774)	($18,101)	$13,063	$130,900	70.3
14	$22,915	$7,962	$8,487	$16,364	$5,050	$493	$687	$0	($5,322)	($1,721)	($18,101)	$36,814	$167,713	69.9
15	$23,374	$8,080	$8,657	$16,282	$4,899	$493	$666	$0	($5,429)	($1,669)	($18,101)	$37,251	$204,965	69.6
16	$23,841	$8,201	$8,830	$16,200	$4,752	$493	$646	$0	($5,537)	($1,619)	$0	$55,807	$260,772	69.2
17	$24,318	$8,323	$9,007	$16,119	$4,609	$493	$627	$0	($5,648)	($1,571)	$0	$56,277	$317,049	68.9
18	$24,804	$8,447	$9,187	$16,039	$4,471	$493	$608	$0	($5,761)	($1,524)	$0	$56,764	$373,813	68.5
19	$25,300	$8,573	$9,371	$15,959	$4,337	$493	$590	$0	($5,876)	($1,478)	$0	$57,268	$431,081	68.2
20	$25,806	$8,701	$9,558	$15,879	$4,207	$493	$572	$0	($5,994)	($1,434)	$0	$57,788	$488,870	67.9
21	$26,322	$8,830	$9,749	$15,799	$4,080	$493	$555	$0	($6,114)	($1,391)	$0	$58,326	$547,195	67.5
22	$26,849	$8,962	$9,944	$15,720	$3,958	$493	$538	$0	($6,236)	($1,349)	$0	$58,880	$606,075	67.2
23	$27,386	$9,095	$10,143	$15,642	$3,839	$493	$522	$0	($6,361)	($1,308)	$0	$59,452	$665,527	66.8
24	$27,934	$9,231	$10,346	$15,564	$3,724	$493	$507	$0	($6,488)	($1,269)	$0	$60,041	$725,568	66.5
25	$28,492	$9,368	$10,553	$15,486	$3,612	$493	$491	$0	($6,617)	($1,231)	$0	$60,647	$786,215	66.2
Total	**$567,391**	**$197,241**	**$210,147**	**$324,957**	**$133,319**	**$12,329**	**$18,134**	**$0**	**($131,780)**	**($45,436)**	**($271,518)**	**IRR 12.92%**	**$786,215**	**1,758.2**

Table 21: *60 Brainerd Rd Financing - 114.3 kW PV, 192.7 kWh BESS*

Year	Annual Energy Efficiency Savings	Annual energy savings from solar PV	T&D Demand Savings	BERDO Savings	Connected Solutions "Active Demand" Revenue	ICAP Savings	Clean Peak Standard Certificate Revenue	SMART Revenue PV + BESS	Annual System Maintenance (2% est.)	Curtailment Service Provider charge	Debt Service	Annual Cash Flow	Cumulative Cash Flow	CO2 reduction (tonnes/yr)
										Total investment:		**($572,463)**	**($572,463)**	
1	$17,692	$16,973	$31,041	$0	$26,266	$1,224	$2,533	$918	($11,473)	($8,640)	($51,488)	$25,047	($547,416)	138.2
2	$18,045	$17,226	$31,662	$0	$25,478	$1,224	$2,457	$914	($11,702)	($8,381)	($51,488)	$25,435	($521,981)	137.5
3	$18,406	$17,483	$32,295	$0	$24,714	$1,224	$2,383	$909	($11,936)	($8,129)	($51,488)	$25,861	($496,120)	136.8
4	$18,774	$17,743	$32,941	$0	$23,972	$1,224	$2,312	$904	($12,175)	($7,885)	($51,488)	$26,323	($469,797)	136.1
5	$19,150	$18,008	$33,600	$0	$23,253	$1,224	$2,242	$900	($12,418)	($7,649)	($51,488)	$26,822	($442,975)	135.4
6	$19,533	$18,276	$34,272	$658	$22,556	$1,224	$2,175	$895	($12,667)	($7,419)	($51,488)	$28,015	($414,960)	134.7
7	$19,924	$18,548	$34,957	$658	$21,879	$1,224	$2,110	$891	($12,920)	($7,197)	($51,488)	$28,587	($386,373)	134.1
8	$20,322	$18,825	$35,656	$658	$21,223	$1,224	$2,047	$887	($13,178)	($6,981)	($51,488)	$29,194	($357,179)	133.4
9	$20,729	$19,105	$36,369	$658	$20,586	$1,224	$1,985	$882	($13,442)	($6,771)	($51,488)	$29,837	($327,342)	132.7
10	$21,143	$19,390	$37,097	$658	$19,968	$1,224	$1,926	$878	($13,711)	($6,568)	($51,488)	$30,517	($296,825)	132.1
11	$21,566	$19,679	$37,839	$9,655	$19,369	$1,224	$1,868	$873	($13,985)	($6,371)	($51,488)	$40,229	($256,596)	131.4
12	$21,997	$19,972	$38,596	$9,655	$18,788	$1,224	$1,812	$869	($14,265)	($6,180)	($51,488)	$40,980	($215,616)	130.8
13	$22,437	$20,269	$39,367	$9,655	$18,225	$1,224	$1,757	$865	($14,550)	($5,995)	($51,488)	($59,853)	($275,470)	130.1
14	$22,886	$20,571	$40,155	$9,655	$17,678	$1,224	$1,705	$860	($14,841)	($5,815)	($51,488)	$42,590	($232,879)	129.4
15	$23,344	$20,878	$40,958	$9,655	$17,148	$1,224	$1,654	$856	($15,138)	($5,640)	($51,488)	$43,450	($189,430)	128.8
16	$23,811	$21,189	$41,777	$20,151	$16,633	$1,224	$1,604	$852	($15,441)	($5,471)	$0	$106,329	($83,101)	128.2
17	$24,287	$21,505	$42,613	$20,151	$16,134	$1,224	$1,556	$847	($15,749)	($5,307)	$0	$107,260	$24,160	127.5
18	$24,773	$21,825	$43,465	$20,151	$15,650	$1,224	$1,509	$843	($16,064)	($5,148)	$0	$108,228	$132,388	126.9
19	$25,268	$22,150	$44,334	$20,151	$15,181	$1,224	$1,464	$839	($16,386)	($4,993)	$0	$109,232	$241,620	126.2
20	$25,773	$22,480	$45,221	$20,151	$14,725	$1,224	$1,420	$835	($16,713)	($4,844)	$0	$110,273	$351,892	125.6
21	$26,289	$22,815	$46,125	$27,649	$14,283	$1,224	$1,377	$831	($17,048)	($4,698)	$0	$118,847	$470,740	125.0
22	$26,815	$23,155	$47,048	$27,649	$13,855	$1,224	$1,336	$826	($17,389)	($4,557)	$0	$119,962	$590,701	124.4
23	$27,351	$23,500	$47,989	$27,649	$13,439	$1,224	$1,296	$822	($17,736)	($4,421)	$0	$121,113	$711,814	123.7
24	$27,898	$23,850	$48,949	$27,649	$13,036	$1,224	$1,257	$818	($18,091)	($4,288)	$0	$122,302	$834,116	123.1
25	$28,456	$24,206	$49,927	$27,649	$12,645	$1,224	$1,219	$814	($18,453)	($4,159)	$0	$123,528	$957,644	122.5
Total	**$566,668**	**$509,622**	**$994,252**	**$290,566**	**$466,684**	**$30,600**	**$45,005**	**$21,629**	**($367,472)**	**($153,507)**	**($772,319)**	**IRR 6.35%**	**$957,644**	**3,254.5**

Table 22: *Examples of multifamily energy efficiency upgrade projects in Massachusetts where program incentives (Mass Save/LEAN) covered most or all the cost. These projects targeted lighting, insulation, HVAC, and appliances in affordable housing*

Building (Location, Units)	Upgrades Implemented	Financing Program	Total Cost	Financing Terms	Estimated Annual Savings	Year
TriTown Landing (Lunenburg, 131 units)	LED lighting, ENERGY STAR refrigerators, low-flow fixtures	Mass Save (Unitil) – 100% incentive rebate	$413000	Owner cost $0 (fully covered by program)	271,000 kWh/year saved (electric)	2021
Agawam 200-unit development	Air sealing, insulation, LED lighting	LEAN Multifamily (Mass Save Low-Income)	$569100	Owner cost $0	$68,641/year; 16,233 therms gas saved	2020
Chestnut Manor (Arlington, ~100 units)	Heat pumps, windows, sliding doors, air sealing	Mass Save/ABCD Low-Income – Eversource & ABCD	$1,300,000	Owner cost $0 (utility/agency investment)	Major reduction in heating energy use	2023

Table 23: *Large-scale deep energy retrofit projects in Massachusetts multifamily housing, involving comprehensive building upgrades and diverse financing*

Project	Major Upgrades	Financing Sources	Total Cost	Financing Terms	Results / Savings	Year (Completion)
Castle Square Apartments (Boston, 500 units)	Insulation shell, reflective roof, HVAC, windows, solar hot water	LIHTC equity, state grants, HUD Green Retrofit grant	$50,500,000	Grants + equity + loans	Heating cost cut from $194k to $50k; electric from $397k to $181k (~$360k/year savings)	2012
Salem Heights Apartments (Salem, 281 units)	Super-insulated panels, electric HVAC, rooftop/facade solar PV	State grant + MassHousing financing	$44,500,000	Grants + affordable housing loans	EUI drop from 111 to 43 kBTU/sf; ~60% energy use reduction	2023

Table 24 shows the input variables for different scenarios at each building. Figures showing visualizations for the differences in each building in each scenario can be found in Task 7: Economic & ROI Analysis, along with explanations on the consistent assumptions and estimates maintained across each scenario, such as solar irradiance, capital costs, energy costs, and annual degree days.

Table 24: *Engineering Inputs, Investments and Outputs for Microgrid Scenarios of Selected Buildings*

Address	Scenario	Engineering Inputs					Investment			Value Output (25 yr Lifespan)		
		PV System Size (kW)	BESS Size (kWh)	ASHP COP	Efficiency Savings (%)	Generator Use (gal)	CapEx ($)	Term (yr)	Interest (%)	NPV ($)	IRR (%)	CO2e Reduction (kg/sqft)
24 Mount Vernon St	Control	10.9	24.6	3.9	5.0	N/A	77,000	15	4.0	804,100	38.7	160.36
624 Hyde Park Ave	Control	44.1	77.6	3.9	5.0	N/A	205,200	15	4.0	526,400	12.9	146.50
60 Brainerd Road	Control	114.3	192.7	3.9	5.0	N/A	572,500	15	4.0	527,800	6.4	50.80
24 Mount Vernon St	85% Roof PV Size	9.3	24.6	3.9	5.0	N/A	72,400	15	4.0	804,200	40.9	158.06
624 Hyde Park Ave	85% Roof PV Size	37.5	77.6	3.9	5.0	N/A	186,800	15	4.0	517,500	13.7	137.25
60 Brainerd Road	85% Roof PV Size	97.2	192.7	3.9	5.0	N/A	524,600	15	4.0	538,500	6.9	46.38
24 Mount Vernon St	90% BESS Size	10.9	22.2	3.9	5.0	N/A	75,800	15	4.0	795,700	38.6	160.36
624 Hyde Park Ave	90% BESS Size	44.1	65.8	3.9	5.0	N/A	201,500	15	4.0	518,600	12.9	146.50
60 Brainerd Road	90% BESS Size	114.3	163.2	3.9	5.0	N/A	563,100	15	4.0	500,700	6.2	50.80
24 Mount Vernon St	110% BESS Size	10.9	27.1	3.9	5.0	N/A	78,100	15	4.0	809,400	38.7	160.36
624 Hyde Park Ave	110% BESS Size	44.1	80.4	3.9	5.0	N/A	209,000	15	4.0	524,000	12.7	146.50
60 Brainerd Road	110% BESS Size	114.3	199.4	3.9	5.0	N/A	581,800	15	4.0	529,600	6.4	50.80
24 Mount Vernon St	No ASHP	10.9	24.6	-	5.0	N/A	66,900	15	4.0	224,700	16.8	45.83

Address	Scenario	Engineering Inputs					Investment			Value Output (25 yr Lifespan)		
		PV System Size (kW)	BESS Size (kWh)	ASHP COP	Efficiency Savings (%)	Generator Use (gal)	CapEx ($)	Term (yr)	Interest (%)	NPV ($)	IRR (%)	CO2e Reduction (kg/sqft)
624 Hyde Park Ave	No ASHP	44.1	77.6	0	5.0	N/A	189,800	15	4.0	108,200	4.9	84.42
60 Brainerd Road		114.3	192.7	0	5.0	N/A	509,700	15	4.0	471,600	6.4	37.61
24 Mount Vernon St	No BESS	10.9	0	3.9	5.0	0.57	85,000	15	4.0	689,200	29.4	155.85
624 Hyde Park Ave		44.1	0	3.9	5.0	2.58	191,200	15	4.0	457,800	11.9	134.08
60 Brainerd Road		114.3	0	3.9	5.0	6.42	518,500	15	4.0	374,300	5.3	44.37
24 Mount Vernon St	No ASHP / No BESS	10.9	0	-	5.0	0.57	74,900	15	4.0	109,700	8.4	41.32
624 Hyde Park Ave		44.1	0	0	5.0	2.58	175,800	15	4.0	39,600	3.1	72.00
60 Brainerd Road		114.3	0	0	5.0	6.42	455,700	15	4.0	307,200	5.1	31.18
24 Mount Vernon St	ASHP COP 2.0	10.9	24.6	2.0	5.0	N/A	70,400	15	4.0	(1,681,400)	-	(125.84)
624 Hyde Park Ave		44.1	77.6	2.0	5.0	N/A	195,200	15	4.0	(976,400)	-	(26.25)
60 Brainerd Road		114.3	192.7	2.0	5.0	N/A	531,400	15	4.0	(3,802,300)	-	(49.58)
24 Mount Vernon St	ASHP COP 2.5	10.9	24.6	2.5	5.0	N/A	72,100	15	4.0	(550,400)	-	4.08
624 Hyde Park Ave		44.1	77.6	2.5	5.0	N/A	197,800	15	4.0	(279,300)	-	53.17
60 Brainerd Road		114.3	192.7	2.5	5.0	N/A	542,200	15	4.0	(1,601,400)	-	(2.04)

Address	Scenario	Engineering Inputs					Investment			Value Output (25 yr Lifespan)		
		PV System Size (kW)	BESS Size (kWh)	ASHP COP	Efficiency Savings (%)	Generator Use (gal)	CapEx ($)	Term (yr)	Interest (%)	NPV ($)	IRR (%)	CO2e Reduction (kg/sqft)
24 Mount Vernon St	ASHP COP 3.0	10.9	24.6	3.0	5.0	N/A	73,800	15	4.0	118,600	9.4	81.12
624 Hyde Park Ave		44.1	77.6	3.0	5.0	N/A	200,500	15	4.0	124,300	5.1	99.58
60 Brainerd Road		114.3	192.7	3.0	5.0	N/A	553,000	15	4.0	(460,700)	-	24.74
24 Mount Vernon St	ASHP COP 3.5	10.9	24.6	3.5	5.0	N/A	75,600	15	4.0	554,100	28.8	131.37
624 Hyde Park Ave		44.1	77.6	3.5	5.0	N/A	203,100	15	4.0	381,600	10.3	129.42
60 Brainerd Road		114.3	192.7	3.5	5.0	N/A	563,800	15	4.0	190,900	3.7	41.48
24 Mount Vernon St	ASHP COP 4.5	10.9	24.6	4.5	5.0	N/A	79,000	15	4.0	1,078,100	49.0	192.33
624 Hyde Park Ave		44.1	77.6	4.5	5.0	N/A	208,400	15	4.0	681,500	15.5	165.17
60 Brainerd Road		114.3	192.7	4.5	5.0	N/A	585,400	15	4.0	858,100	8.8	57.57
24 Mount Vernon St	No Insulation / Envelope	10.9	24.6	3.9	0.0	N/A	52,500	15	4.0	833,400	56.7	150.50
624 Hyde Park Ave		44.1	77.6	3.9	0.0	N/A	176,200	15	4.0	522,200	14.5	134.42
60 Brainerd Road		114.3	192.7	3.9	0.0	N/A	475,500	15	4.0	627,500	8.2	45.74
24 Mount Vernon St	Low Interest Loan	10.9	24.6	3.9	5.0	N/A	77,000	15	2.5	811,500	39.4	160.36
624 Hyde Park Ave		44.1	77.6	3.9	5.0	N/A	205,200	15	2.5	548,800	13.5	146.50

Address	Scenario	Engineering Inputs					Investment			Value Output (25 yr Lifespan)		
		PV System Size (kW)	BESS Size (kWh)	ASHP COP	Efficiency Savings (%)	Generator Use (gal)	CapEx ($)	Term (yr)	Interest (%)	NPV ($)	IRR (%)	CO2e Reduction (kg/sqft)
60 Brainerd Road	Low Interest Loan	114.3	192.7	3.9	5.0	N/A	572,500	15	2.5	592,300	7.1	50.80
24 Mount Vernon St	High Interest Loan	10.9	24.6	3.9	5.0	N/A	77,000	15	7.5	785,400	37.2	160.36
624 Hyde Park Ave	High Interest Loan	44.1	77.6	3.9	5.0	N/A	205,200	15	7.5	469,500	11.4	146.50
60 Brainerd Road	High Interest Loan	114.3	192.7	3.9	5.0	N/A	572,500	15	7.5	363,600	4.9	50.80
24 Mount Vernon St	No HEAT Loan	10.9	24.6	3.9	5.0	N/A	77,000	15	0% / 4%	799,800	38.4	160.36
624 Hyde Park Ave	No HEAT Loan	44.1	77.6	3.9	5.0	N/A	205,200	15	0% / 4%	521,800	12.8	146.50
60 Brainerd Road	No HEAT Loan	114.3	192.7	3.9	5.0	N/A	572,500	15	0% / 4%	520,300	6.4	50.80

The scenario outputs from Table 24 were calculated using a modeling template developed for this report. Table 25 and Table 26 show the inputs and intermittent outputs, using the control example at 60 Brainerd Rd, performed along the way to provide the annualized system lifespan assessment for financials and CO2 emissions of the proposed systems. The outputs for these scenarios are tabulated according to the setup of Table 19, Table 20, and Table 21.

Along with inputs and intermittent variables, precedents and dependencies for each are shown, demonstrating which inputs are sourced directly, which are assumed, and which are calculated from other values along the way.

Table 25: *Microgrid Financial and Sustainability Model Template*

Metric	Input Value	Units	Precedents	Dependents
Interest rate:	4%	Percent (%)		Debt Service
Term:	15	Years		Debt Service
Calculation of Clean Peak Standard certificates:	Input Value	Units	Precedents	Dependents
Average value of each CPS Certificate over 10 year period	$30	Dollars ($)		CPS Revenue
Curtailment Service Provider (CSP) Fee	30%	Percent (%)		Curtailment Service Provider Charge
System Maintenance Annual Escalator	102%	Percent (%)		Annual System Maintenance
Site historic data:	Input Value	Units	Precedents	Dependents
Peak Building Monthly Demand	212.3	kW	Peak Day kWh [14] [60]	Average building monthly demand, ICAP savings potential
Average Building Monthly Demand	106.1	kW	Peak Building Monthly Demand	Avg. customer monthly peak demand, Annual System Maintenance, Carbon reduction
Typical use estimate (no electric heating)	6.32	kWh per square feet	Annual kWh consumed, approximate sqft	Emissions per sqft
Average HDD	5451		[60]	Saved Fuel consumption converted to Electrical Expense,
Average CDD	791		[60]	Electricity save on Cooling
Parameters:	Input Value	Units	Precedents	Dependents
Average savings of energy (from insulation, envelope, etc.)	5.0%	Percent (%)		EE savings (electric, kWh), Emission reduction from insulation, Annual Energy Savings from EE improvements
Average price of electricity	$0.303	Dollars per kWh billed ($)	[63]	Annual Energy Savings from EE improvements, Annual energy savings from solar energy production
Inflation rate of energy tariffs	2%	Percent per year (%)		Annual Energy Savings from EE improvements, Annual energy savings from solar energy production, T&D Savings, Present Value
Average conversion of heating fuel to electric	100.0%	Percent (%)		EE savings (electric heating), Emission reduction from insulation
Average price of heating fuel	$2.111	Dollars per therm_nat gas billed ($)	[25] [35] [64] [62]	Annual Energy Savings from EE improvements
Air-Source Heat Pump Coeff. Of Performance	3.9			ASHP EER, ASHP Cost, Saved Fuel consumption converted to Electrical Expense, Emission reduction from insulation
Air-Source Heat Pump EER	15.4		ASHP COP	Electricity saved on Cooling
Air-Source Heat Pump Cost	89619	Dollars ($)	ASHP COP	Zero-interest HEAT Loan, Total Investment Estimate in ASHP, Annual Cash Flow (Year 13)
Saved Fuel consumption converted to Electrical Expense	15,103	therm fuel saved, annual	Average HDD, ASHP COP, [14]	EE savings (electric heating), Annual Energy Savings from EE Improvements
	113,494	kWh of converted heating source, annual	Average HDD, ASHP COP, [14]	Total investment estimate in BESS and microgrid controller, EE savings (electric heating), Emission reduction from insulation, Annual Energy Savings from EE Improvements

Parameters:	Input Value	Units	Precedents	Dependents
Electricity saved on Cooling	46,385	kWh of cooling source, annual	Average CDD, ASHP EER, [14]	EE savings (electric), Annual Energy Savings from EE improvements
Solar energy savings estimator:	Input Value	Units	Precedents	Dependents
Estimated PV power output, AC	114.3	Kilowatt (kW)	[16]	Solar kWh as % of Building kWh, Total investment estimate in Solar, Solar savings (electric), SMART Revenue, Annual energy savings from solar energy
Average annual effective hours output	1318	Hours	[16]	Solar kWh as % of Building kWh, SMART Revenue, Annual energy savings from solar energy
Coincidence factor	100%	Percent (%)		Annual energy savings from solar energy production
Solar kWH as % of Building kWh	37%	Percent (%) (cannot be greater than 100%)	Estimated PV power output (AC), Avg. annual effective hours output, Annual kWh consumed	Avg. peak load displaced with PV potential, Annual energy savings from solar energy production
SMART Payment per kWh produced by PV	$0.01	Dollars per kWh produced	[26]	SMART Revenue
SMART Payment BESS Adder	$0.00	Dollars per kWh produced	[26]	SMART Revenue
Demand charge (T&D) savings estimator:	Input Value	Units	Precedents	Dependents
Average customer monthly peak demand	106.1	Kilowatt (kW)	Average Building Monthly Demand	Total T&D charges per monthly peak kW, ICAP savings
Cost per kW from bill analysis	$36	Dollars per kW ($)	[73]	Total T&D charges per monthly peak kW
Total T&D charges per monthly peak kW	$3,449	Dollars per kW ($)	Average customer monthly peak demand, Cost per kW from bill analysis	T&D Demand Savings
Estimated average demand reduction	75%	Percent (%)		T&D Demand Savings
Connected Solutions "Active Demand" response incentive payments for performance:	Input Value	Units	Precedents	Dependents
PV Annual Percentage Derate Factor	0.5%	Percent (%)		Annual energy savings from solar energy production, SMART Revenue, Carbon reduction
Battery Annual Percentage Derate Factor	3%	Percent (%)		ConnectedSolutions Response Savings, Clean Peak Standard Revenue
Daily dispatch participation (summer)	$275	Dollars per kW ($)	[53]	ConnectedSolutions Response Savings
Winter targeted dispatch	$50	Dollars per kW ($)	[53]	ConnectedSolutions Response Savings
% of battery capacity dispatched	90%	Percent (%)		ConnectedSolutions Response Savings
Installed capacity (ICAP) savings estimator:	Input Value	Units	Precedents	Dependents
% of total ISO-NE load assumed to participate in ICAP savings	50%	Percent (%)	[73]	ICAP Savings
ISO-NE average cost/kW-year	$108	Dollars ($)	[73]	ICAP Savings
The ICAP savings potential per customer	21%	Percent (%)	Peak Building Monthly Demand, Avg. kWh/hour	ICAP Savings
Total Investment Estimate:	Input Value	Units	Precedents	Dependents
Rate of investment in BESS and microgrid controller	$693	Dollars per kWh ($)	[34]	Total investment estimate in BESS and microgrid controller

Total Investment Estimate:	Input Value	Units	Precedents	Dependents
Duration of BESS and microgrid controller	4.25	Hours		Total investment estimate in BESS and microgrid controller, ConnectedSolutions Response Savings, Clean Peak Standard Revenue, Annual System Maintenance, Carbon reduction
Installed cost of solar	$ 3,990	Dollars per kW ($)		Total investment estimate in Solar
Generator Investment	$ 0	Dollars ($)	Duration of BESS and microgrid controller	Total investment estimate in EE
Other investment	$ 97,000	Dollars ($)		Total investment estimate in EE
Zero-Interest HEAT Loan	$ -	Dollars ($)	ASHP Cost	Debt Service
Annual Emission Reduction	**Input Value**	**Units**	**Precedents**	**Dependents**
CO2 emissions per MWh of New England grid generation dispatched on average	0.53	Metric tons per MWh	[15]	Emission reduction from electric EE, EE savings (electric heating), Emission reduction from insulation, Emission reduction from solar display
CO2 emissions per Fuel Source Burned	0.0093	Metric Ton per gal	[15]	EE savings (electric heating)
Total Building Emissions	143405	kgCO2e	[14]	BERDO Savings, Carbon reduction, Expected Building Emissions, Building emissions per sqft
Building Emissions per sqft	12.2	kgCO2e	Total Building Emissions, approximate sqft	BERDO Savings
Number of Units in Building	24.0		[29] [30] [31]	BERDO Savings
Insert Label	**Input Value**	**Units**	**Precedents**	**Dependents**
Average monthly kWh billed to customer from utility bill analysis	33,728	kWh	Annual kWh consumed	Avg. kWh/day, EE savings (electric), Annual Energy Savings from EE Improvements
Average kWh/day	1088	kWh	Average monthly kWh billed to customer from utility bill analysis	Avg. kWh/hour
Average kWh/hour	45.33	kWh	Avg. kWh/day	ICAP savings potential per customer, Avg. kWh for 4 hours, MWh for 1 hour, Monthly System Peak
Average kWh for 4 hours	181.3	kWh	Avg. kWh/hour	Summer and Winter Max CPS, Spring and Fall Max CPS
MWh for 1 hour	0.045	MWh	Avg. kWh/hour	MWh for 4 hours
annual kWh consumed	404,731	kWh	[14]	Solar kWh as % of Building kWh, Avg. Monthly kWh billed to customer from utility bill, Total investment estimate in BESS and microgrid controller
approximate sqft	64,079	sqft	[14]	Building Emissions per sqft, Expected Building CO2/yr/sqft
Total Investment Estimate:	**Input Value**	**Units**	**Precedents**	**Dependents**
Total investment estimate in EE	$97,000	Dollars ($)	Generator investment, Other investment	Total investment, Annual Cash Flow
Total investment estimate in BESS and microgrid controller	$101,217	Dollars ($)	Saved Fuel consumption converted to Electrical Expense, Rate of Investment in BESS and controller, Duration of BESS and controller, annual kWh consumed, Solar savings (electric) EE savings (electric)	Total IRA Eligible investment, Total Investment

Total Investment Estimate:	Input Value	Units	Precedents	Dependents
Total investment estimate in Solar	$456,057	Dollars ($)	Estimated PV power output (AC), Installed cost of solar	Total IRA Eligible investment, Total Investment
Total investment estimate in ASHP	$89,619	Dollars ($)	ASHP Cost	Total IRA Eligible investment, Total Investment
Total IRA Eligible investment	$646,893	Dollars ($)	Total investment estimate in BESS and microgrid controller, Total investment estimate in Solar, Total investment estimate in ASHP	Annual Cash Flow
Investment Tax Credit available in IRA	30%	Percent (%)	[70]	Annual cash flow
Total investment	$743,893	Dollars ($)	Total investment estimate in EE, Total investment estimate in BESS and microgrid controller, Total investment estimate in Solar, Total investment estimate in ASHP	
Annual Emissions Reduction Calculation	Input Value	Units	Precedents	Dependents
EE savings, electric	66,622	kWh per year	Avg. savings of energy (from insulation, envelope), Electricity saved on Cooling, Avg. monthly kWh billed from utility bill analysis	Total investment estimate in EE, Emission reduction from electric EE
Emission reduction from electric EE	35.3	tonnes/yr	EE savings (electric), CO2 emissions per MWh of grid generation	Carbon reduction
EE savings, electric heating	20.0	tonnes/yr	Avg, conversion of heating fuel to electric, Saved fuel consumption converted to Electrical Expense, CO2 emissions per MWh grid generation	Carbon reduction
Emission reduction from insulation	3.9	tonnes/yr	Avg. savings of energy (from insulation, envelope), Avg. conversion of heating fuel to electric, ASHP COP, Saved Fuel consumption converted to Electrical Expense, CO2 emissions per MWh grid generation	Carbon reduction
Solar savings, electric	150,647	kWh	Estimated PV power output (AC), Avg. annual effective hours output	Total investment estimate in BESS and controller, Emission reduction from solar displ.
Emission reduction from solar displ.	79.8	tonnes/yr	Solar savings (electric), CO2 emissions per MWh grid generation	

Table 26: *ISO New England Clean Peak Standard Certificate Revenue Calculations [73]*

Max CPS if full battery kWh is discharged to cover site historical peaks for all Seasonal and Monthly Peak Events	Average kWh/ Event Period	Multipliers	Events/ Year	Hours/ Event	Certificates
Summer and Winter	181	4	125	4	22.67
Spring and Fall	181	1	125	4	5.67
Monthly System Peak	45	25	12	1	13.60
Resilience during Four Seasonal Peak Periods only	N/A	1.5	N/A	N/A	42.50
Total Annual Certificates					**84**