Boston Building Emissions Performance Standard

Technical Methods Overview

Prepared for City of Boston

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CONTENTS

ACKNOWLEDGEMENTS II

1. INTRODUCTION 1

2. BUILDING EMISSIONS ANALYSIS AND POLICY DESIGN 4
   - 2.1. Local building typologies 4
   - 2.2. Determinants of building energy use and emissions by typology 6
   - 2.3. Fuel, energy, and emission profiles by building typology 7
   - 2.4. Policy design 11
   - 2.5. Performance standard targets 12
   - 2.6. Policy impact on emissions over time 15

3. BUILDING DECARBONIZATION PATHWAYS 17
   - 3.1. End-use energy, emissions, and equipment profiles by typology 17
   - 3.2. Decarbonization strategies 20
   - 3.3. Pathways to net-zero carbon and levelized cost of abatement 25
   - 3.4. Low-carbon district thermal system case studies 27

APPENDIX A. SCENARIOS AND SENSITIVITIES A-1

APPENDIX B. GLOSSARY B-1

APPENDIX C. ABBREVIATIONS C-1

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1. INTRODUCTION

The City of Boston has committed to achieving carbon neutrality by 2050 and has determined that addressing emissions from energy use in existing large- and medium-sized buildings will be a crucial aspect of attaining this goal. In the City's Climate Action Plan, it called for a greenhouse gas (GHG) emissions performance standard:[1]

> [The performance standard] will require that all buildings larger than a certain threshold meet fixed carbon targets that decrease over time. Performance standards specific to different building typologies will ensure that buildings make steady progress on emissions reductions, while allowing building owners to develop solutions that are cost-effective and appropriate for the building's use.

Strategies to reduce emissions include retrofitting existing building to be more energy efficient, producing and purchasing renewable energy to power building operations, and switching away from fuels that cause GHG emissions (for instance, by electrifying end-uses of energy that rely on combustion of fossil fuels).

The City of Boston commissioned Synapse Energy Economics (Synapse) to perform an in-depth building energy and emissions analysis to develop a framework and estimate cost impacts for mandatory greenhouse gas (GHG) emissions targets by building type that decrease over time. The City of Boston also tasked Synapse with convening and facilitating discussions with a technical advisory group (TAG) of experts in building science, architecture, engineering, construction, building operations, energy policy, renewable energy, and affordable housing. Using information provided by the City, the TAG, and its own analysis, Synapse prepared policy recommendations, including proposed emissions targets by building type, example compliance strategies, and compliance cost estimates. This analysis and the proposed building emissions performance standard build upon the policy foundation established in the City's 2013 Building Energy Reporting and Disclosure Ordinance (BERDO). BERDO requires owners of large buildings to report their annual energy and water use to the City for public disclosure.

Our analysis uses Synapse's building energy and emissions performance analysis model to evaluate how the City of Boston can strategically design its building emissions performance standard to cost-effectively meet the 2050 GHG target and interim goals. The model uses raw data from local buildings to create a "bottom-up" assessment of all energy consumed and emissions produced through operation of large- and medium-sized buildings within the City. We analyze a series of scenarios and sensitivities to

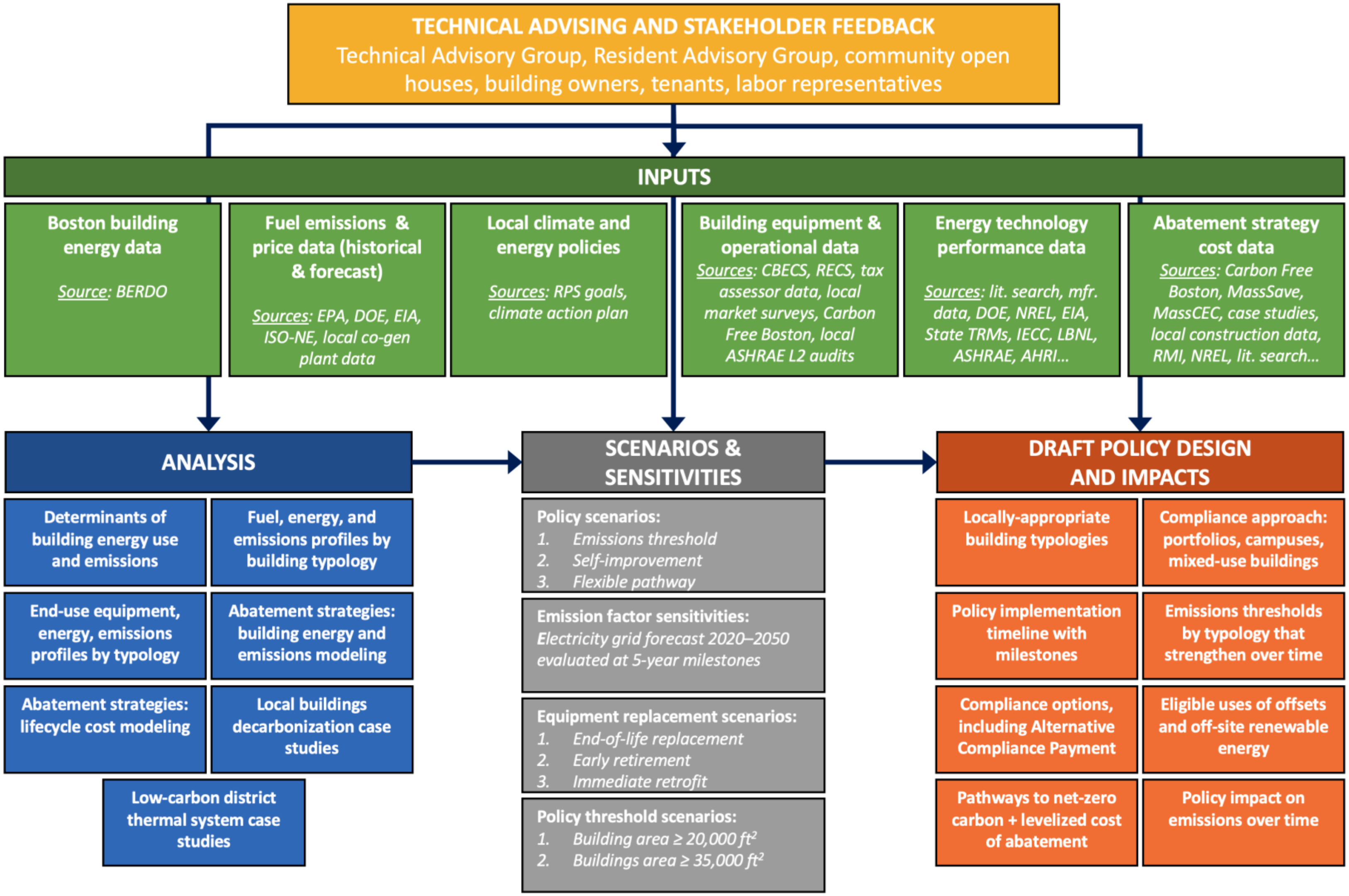
[1] City of Boston. 2019. *Climate Action Plan: 2019 Update*. Available at: https://www.boston.gov/sites/default/files/embed/file/2019-10/city_of_boston_2019_climate_action_plan_update_4.pdf. Pages 44-46.

compare the long-term decarbonization impacts of various policy designs and develop concrete GHG reduction pathways for Boston's building stock. The results of this analysis provide an initial framework for the City to consider discrete policy options, identify areas for further analysis, and evaluate concrete next steps towards its 2050 climate goal.

This report provides an overview of the technical methods and key inputs used in the in-depth building energy and emissions analysis, policy development, and estimation of cost impacts for the building emissions performance standard. The results of the study and supporting documentation are provided in the supplementary materials, which include Synapse presentations to the TAG, minutes from TAG meetings, TAG survey results, and Synapse model inputs and outputs.[2] Figure 1 illustrates the relationship among the various aspects of this study.

[2] Publicly available materials are posted on the City of Boston's website: City of Boston. 2019. *Developing Carbon Targets for Existing Large Buildings.* Available at: https://www.boston.gov/departments/environment/developing-carbon-targets-existing-large-buildings

Figure 1. Synapse building emissions performance modeling framework



2. BUILDING EMISSIONS ANALYSIS AND POLICY DESIGN

The local building stock was responsible for more than two-thirds of GHG emissions in Boston in 2018.[3] These emissions result primarily from the consumption of electricity, combustion of natural gas and fuel oil associated with operation of the buildings, and use of district heating and cooling. Synapse's analysis focuses on developing and informing the design of Boston's building emissions performance standard by understanding the sources of GHG emissions across large- and medium-sized buildings, evaluating strategies and the associated costs to reduce those emissions to zero by 2050, and identifying emissions targets that decrease over time.

2.1. Local building typologies

Energy use and emissions vary considerably building-to-building, even after accounting for different building sizes. The activities that occur within a building greatly influence that building's energy use intensity and emissions intensity. Thus, the City of Boston's emissions performance standard will be designed to vary by building type, with appropriate targets for one group (*e.g.,* healthcare facilities) differing from those for another (*e.g.,* office buildings). The grouping of building types is fundamental to the policy design.

Synapse and the TAG identified 13 locally appropriate building typologies using the following process:

1. Begin with the existing building type categorization inherent to Energy Star Portfolio Manager (ESPM),[4] the reporting tool used for BERDO compliance. ESPM has three levels of categorization for every building: a detailed building type, a higher-level building type, and a highest-level building category.

Energy use intensity (EUI) is the energy use per square foot at a property. EUI is a common metric for comparing the energy use across differently sized buildings.

Emissions intensity is the amount of emissions of carbon dioxide released per unit of another variable, such as gross floor area, gross domestic product, output energy use, or transport. In this report we use emissions per square foot at a property to compare the emissions across differently sized buildings.

To estimate emission intensity of a building, we use the following formula:

$$EMI_{it} = \frac{\sum(E_{ijt} \times EF_{jt})}{GFA_i}$$

where:

EMI_{it} is the calculated emissions intensity of building i in year t

E_{ijt} is the energy use in building i of fuel type j in year t

EF_{jt} is the emission factor for fuel type j in year t

GFA_i is the ESPM-calculated gross floor

[3] Hatchadorian, R., Best, R., Wholey, K., Calven, A., Levine, E., Tepfer, S., Swett, B., Walsh, M.J., Pollack, A., Perez, T., Castigliego, J.R., and Cleveland, C.J., 2019. *Carbon Free Boston: Buildings Technical Report.* Boston University Institute for Sustainable Energy. Available at http://sites.bu.edu/cfb/technical-reports.

[4] *Energy Star Portfolio Manager* is a no-cost, web-based energy management tool that allows users to track and assess energy and water consumption across a portfolio of buildings.

2. For ESPM detailed building types that fall under more than one high-level category (*e.g.,* convenience stores fall under both "retail" and "food sales & service") eliminate the duplication by assigning the building subtype to a single category.

3. Use the highest-level category that does not eliminate important distinctions in use type or emissions intensity.

4. Adjust grouping based upon BERDO emissions intensity by consolidating similar building types that have similar emissions intensities and separating building types that have very different emissions intensities.

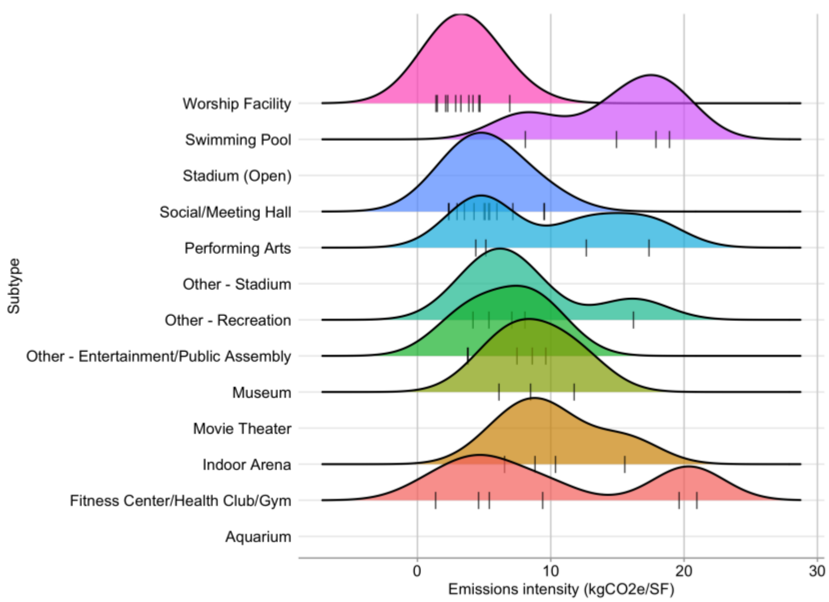
5. Adjust groupings based on number of BERDO buildings and consolidate similar building use types with relatively few buildings. Allow building types with many buildings to remain separate.

6. Eliminate umbrella categories (*i.e.,* "mixed use" and "other").

7. Where the most appropriate grouping is unclear under the ESPM categorization, use the taxonomies of the U.S. Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS) and the International Code Council's International Building Code (IBC) as guides.

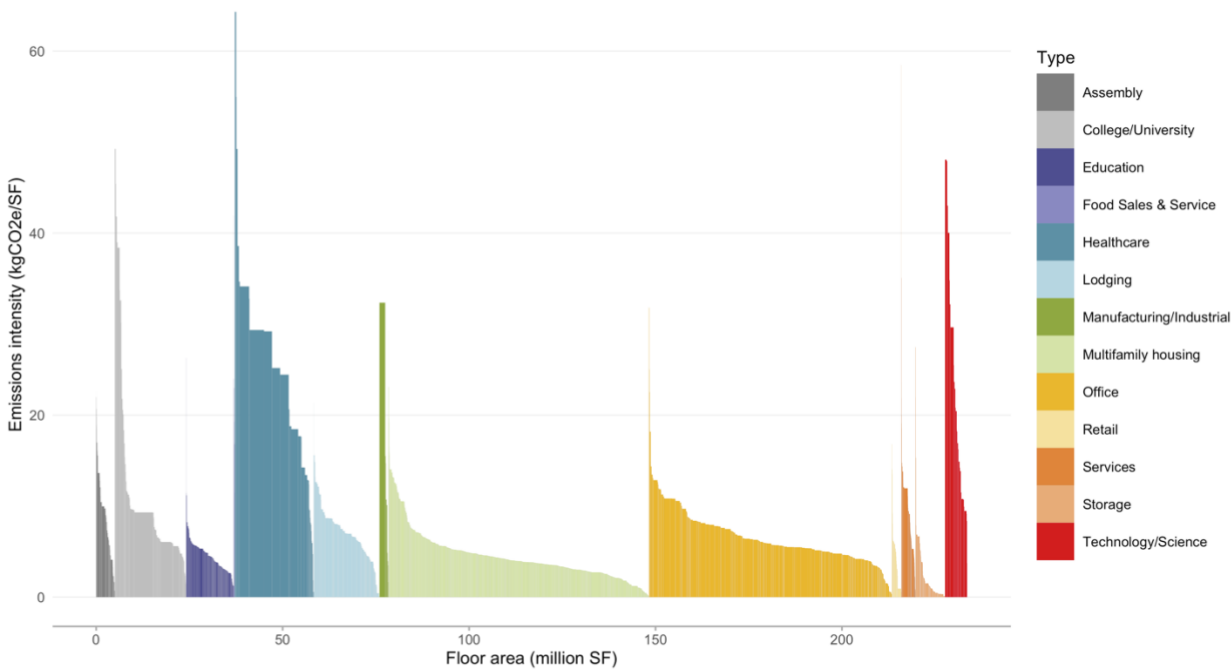
The TAG recommended 13 building use typologies, including typology assignment of the 85 ESPM subtypes. These results are provided in the supplementary materials. Figure 2 depicts a sample comparative analysis used to adjust the typology groupings based upon BERDO emissions intensity and number of local buildings in each building subtype. We show the relative emissions intensity distributions of all BERDO buildings, categorized by typology in Figure 3.

Figure 2. Assembly building emissions intensity by subtype, BERDO 2018 data



Source: Synapse model using BERDO data. Note: Subtypes with only one building do not have a distribution plot. Small vertical lines indicate the emissions intensity of individual buildings.

Figure 3. Building emissions intensity by typology, BERDO 2018 data

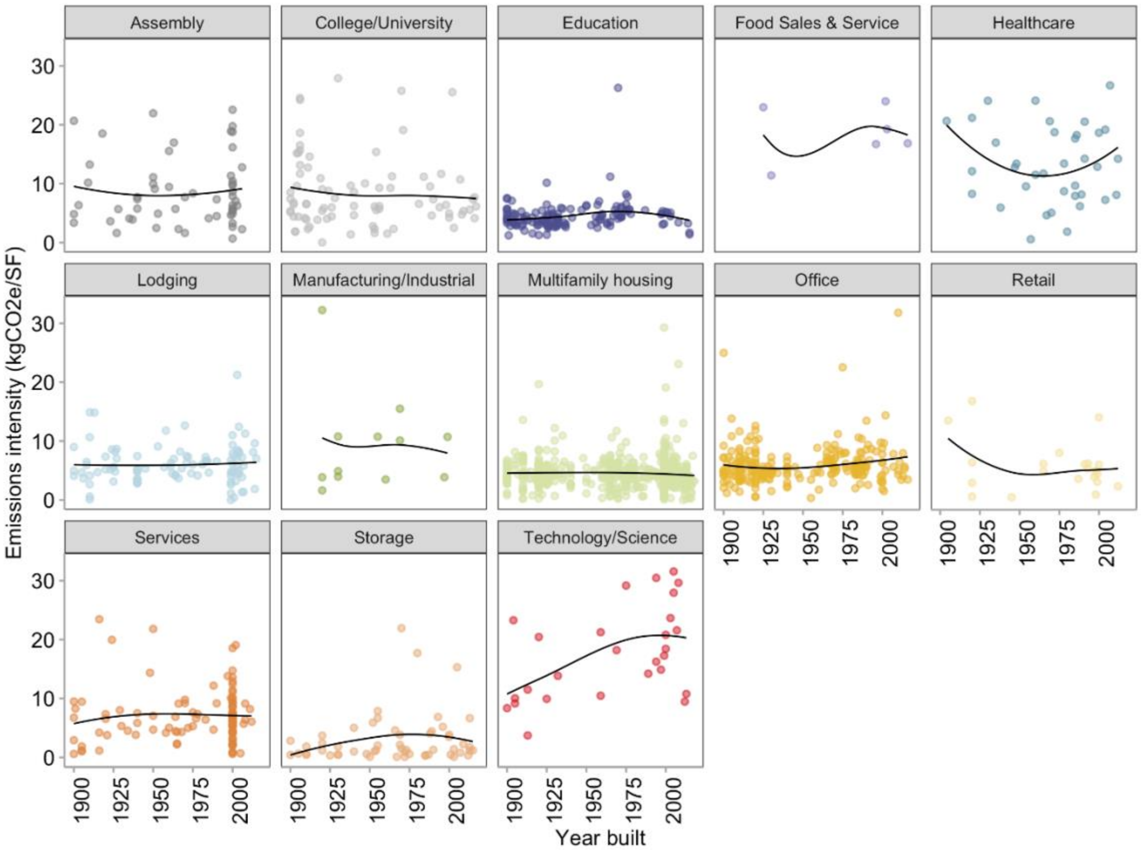


Source: Synapse model using BERDO data. Individual buildings (n = 1502) are plotted as vertical bars, with width proportionate to gross floor area and height proportionate to emission intensity.

2.2. Determinants of building energy use and emissions by typology

Should Boston's performance standard regulate emissions solely based on building typology? Are there other important determinants of emissions that the policy should consider? To answer these questions, Synapse and the TAG studied correlations between emissions and a range of building characteristics. Using the BERDO dataset, we controlled for the impact of building typology to isolate the effect of building size, percent occupancy, building age, fuel source, and time-variant effects. Figure 4 shows an example of this analysis, identifying trends in emissions intensity by the year the building was built for each of the 13 building typologies. Based on the results of this analysis, Synapse and the TAG recommended that the performance standard targets be based principally on building typology, and that other factors that pose a substantial obstacle to compliance should be considered by the City or a review board on a case-by-case basis.

Figure 4. Emissions intensity in BERDO buildings by year built, 2018 data

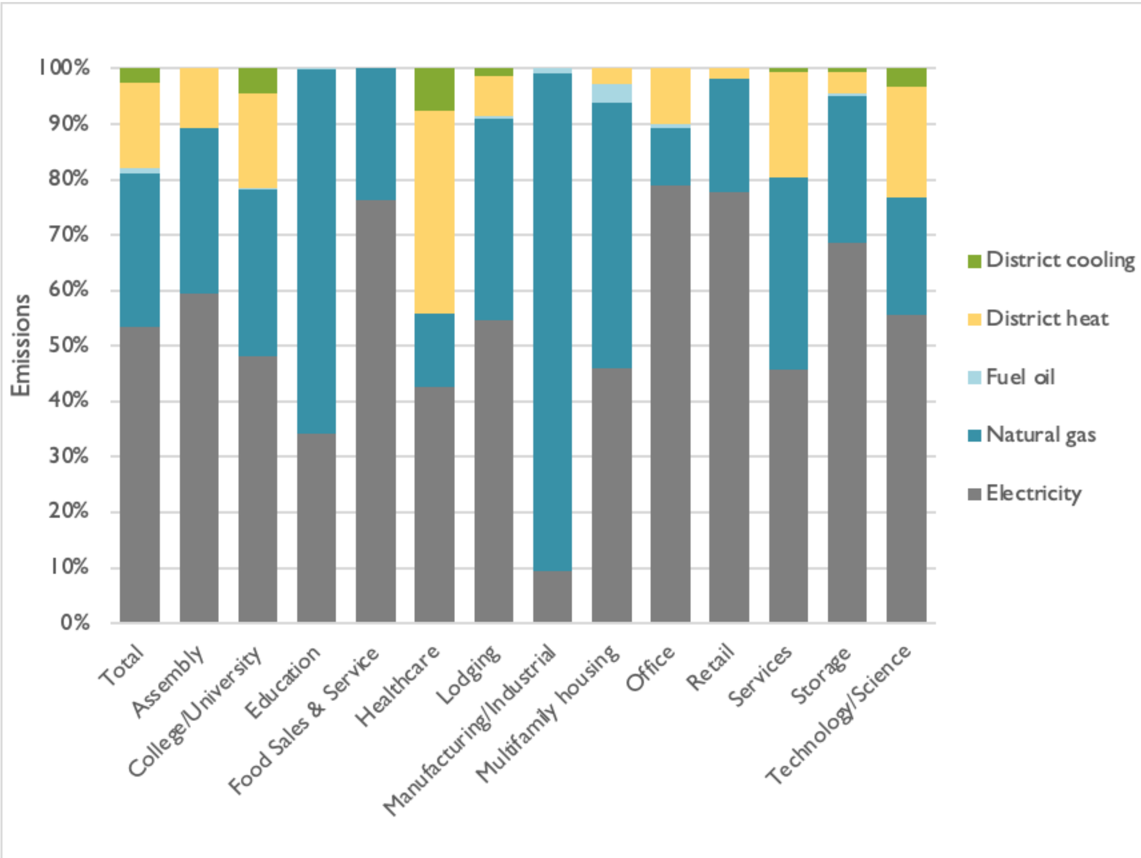


Source: Synapse model using BERDO data. The trendline is prepared using a locally weighted regression statistic. Across the 13 building typologies, emissions intensity does not vary consistently with the year the building was built. Due in part to this result, the TAG did not recommend including building age as a factor in establishing performance targets.

2.3. Fuel, energy, and emission profiles by building typology

The GHG emissions associated with operating a building result primarily from combustion of fossil fuels—this includes onsite combustion of fuels such as natural gas for space heating and water heating, as well as onsite use of electricity, district heating, and district cooling that were generated by an offsite central plant running on fossil-based fuels. To quantify the current emissions of buildings in Boston and develop strategies to reduce those emissions requires understanding the fuel profiles of the local building typologies. Synapse and the TAG analyzed the BERDO data to develop fuel, energy, and emission profiles for buildings covered by the BERDO policy, such as the result shown in Figure 5.

Figure 5. Emissions profiles in BERDO buildings by fuel type and building typology, 2018 data



Source: Synapse model using BERDO data.

To create the fuel, energy, and emissions profiles, we aggregate the energy use data by fuel type for each building typology and applied fuel-specific energy content and emission factors to quantify the associated emissions.[5] The fuel emission factors used in this study rely upon the ESPM Technical Reference for Greenhouse Gas Emissions[6] and the annual ISO New England (ISO-NE)[7] Electric Generator Air Emissions Reports.[8] These are summarized in Table 1 below.

[5] An emission factor is a value for scaling emissions to energy or activity data. Emission factors are commonly presented in terms of a standard rate of emissions per unit of energy or activity (e.g., grams of carbon dioxide emitted per kilowatt-hour of electricity used).

[6] U.S. Environmental Protection Agency. 2020. *Energy Star Portfolio Manager Technical Reference for Greenhouse Gas Emissions*. Available at: https://portfoliomanager.energystar.gov/pdf/reference/Emissions.pdf.

[7] ISO New England, Inc. is the independent, non-profit Regional Transmission Organization serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

[8] ISO New England Inc. 2020. *Environmental and Emissions Reports*. Available at: https://www.iso-ne.com/system-planning/system-plans-studies/emissions.

Table 1. Fuel emission factors used in the building performance standard analysis

Fuel type	Emission factor (kg CO_2e/MMBtu)
Natural Gas	53.11
Fuel Oil (No. 1)	73.50
Fuel Oil (No. 2)	74.21
Fuel Oil (No. 4)	75.29
Diesel Oil	74.21
District Steam	66.40
District Hot Water	66.40
Electric Driven Chiller	52.70
Absorption Chiller using Natural Gas	73.89
Engine-Driven Chiller Natural Gas	49.31
Grid electricity, 2018	87.50

While some fuel emission factors remain relatively constant over time, as they are related to fixed physical properties of the fuel, other emission factors can change as the fuel mix changes. For example, as more renewable energy[9] sources are added to the power grid, the emissions associated with the average unit of electricity used in buildings decrease. We estimate electricity emission factors for years 2019 through 2050, shown in Table 2, assuming 80 percent of the electricity supply in 2050 originates from clean energy[10] sources in alignment with the Massachusetts Clean Energy Standard[11] and the clean energy policies of other states in ISO-NE. We also assume that the average emission factor of the non-clean energy sources in the grid remains the same. We used the following formula to estimate electricity emission factors.

$$EF_t = EF_{t0} \times \frac{1 - CES_t}{1 - CES_{t0}}$$

where:

EF_t is the electricity emission factor in year t

[9] Renewable energy is a group of energy sources that emit low-to-no direct greenhouse gases. Renewable energy is generated from renewable resources, such as solar, wind, geothermal, hydrokinetic energy, hydropower, and biomass.

[10] Clean energy is a group of energy sources that emit low-to-no greenhouse gas emissions. Clean energy includes nuclear power and carbon capture and storage in addition to renewables, such as solar, wind, and biomass. Distinction between clean energy and renewables is often defined by statute.

[11] Beginning in 2018, the Clean Energy Standard establishes a minimum percentage of in-state procurement of electricity that must originate from clean energy sources. The minimum percentage begins at 16 percent in 2018 and increases 2 percent annually to 80 percent in 2050.

EF_{t0} is the electricity emission factor in the baseline year, 2018

CES_t is the Clean Energy Standard minimum percentage of procurement of electricity that must originate from clean energy sources in year t

CES_{t0} is the Clean Energy Standard minimum percentage of procurement of electricity that must originate from clean energy sources in the baseline year, 2018

Table 2. Electricity emission factors used in the building performance standard analysis

Year	lb/MWh	kg/MMBtu
2018	658	87
2019	642	85
2020	627	83
2021	611	81
2022	595	79
2023	580	77
2024	564	75
2025	548	73
2026	533	71
2027	517	69
2028	501	67
2029	486	65
2030	470	62
2031	454	60
2032	439	58
2033	423	56
2034	407	54
2035	392	52
2036	376	50
2037	360	48
2038	345	46
2039	329	44
2040	313	42
2041	298	40
2042	282	37
2043	266	35
2044	251	33
2045	235	31
2046	219	29
2047	204	27
2048	188	25
2049	172	23
2050	157	21

Synapse and the TAG evaluated whether to apply local emission factors specific to Boston-area district energy systems for buildings consuming locally generated electricity, steam, and chilled water. Ultimately, we decided to use generic factors from ESPM, due to a number of constraints as follows:

- Based upon (a) a review of the Massachusetts Department of Environmental Protection's technical support documentation for the calculation of GHG emission factors for district energy systems[12] and (b) discussions with operators and customers of local district energy systems, there does not appear to be a standard methodology for attributing emissions across the various outputs (*e.g.,* electricity, steam, and chilled water) generated by individual district energy systems.
- There are numerous local campus and district energy systems, and emissions factors are not readily available for all of them.
- There are data gaps that prevent a comprehensive mapping of buildings to the district energy systems that serve them.

2.4. Policy design

Synapse conducted a series of polls and feedback sessions to review key design aspects for the performance standard policy. Synapse, the TAG, and the City of Boston considered a range of aspects, including:

- **Policy approach**—how should the targets be set? Should the performance standard establish, for example, fixed emission thresholds (*e.g.,* kilograms of carbon dioxide equivalent per square foot of building area) by typology that decrease over time or individual compliance targets that require buildings to reduce emissions by relative (percentage-based) amounts over time?
- **Timeline**—when should the policy begin and how frequently should the emission targets decrease over time? The TAG considered how policy timelines would interact with capital planning cycles, tenant leases, and equipment life cycles.
- **Size threshold**—what should be the minimum-size building regulated by the policy? The 2013 BERDO policy applies to all City-owned buildings, buildings at least 35,000 square feet, buildings with at least 35 residential units, and multiple buildings on a parcel that together comprise at least 50,000 square feet (residential) or 100,000 square feet (commercial). The TAG evaluated the administrative and emissions impact of lowering these size thresholds.
- **Occupancy and density**—how can the policy be designed to avoid creating hardship for buildings with high occupant density? Synapse and the TAG identified that there are

[12] See, for example, Massachusetts Department of Environmental Protection. 2020. *Draft 2018 Greenhouse Gas Emission Factors to be used by Retail Sellers of Electricity Reporting under 310 CMR 7.75(9)(c) "Greenhouse Gas Emissions Reporting."* Available at https://www.mass.gov/doc/technical-support-document-draft-2018-ghg-emission-factors/download.

substantial data gaps and differences in occupancy/density metrics across the 13 typologies, which make creating a one-size-fits-all approach to density challenging. Thus, TAG did not recommend formally incorporating an adjustment to the performance standard for occupancy and density at this time.

- **Affordable housing and disadvantaged communities**—how can the policy aid owners of affordable housing in achieving compliance? How can the policy be designed to reduce economic hardship and risk of displacement for residents? Can the policy improve health outcomes and create jobs that benefit disadvantaged communities?

- **Other policy dimensions—**how does the policy apply to portfolios of buildings, campuses, and mixed-use buildings? How does the policy interact with historic preservation requirements? Should the policy account for avoided emissions resulting from off-site renewable energy purchase and carbon offsets, and if so, how? Should the performance standard include emissions from emergency backup power? How should expected future changes in electricity grid emissions be accounted for when designing emission targets?

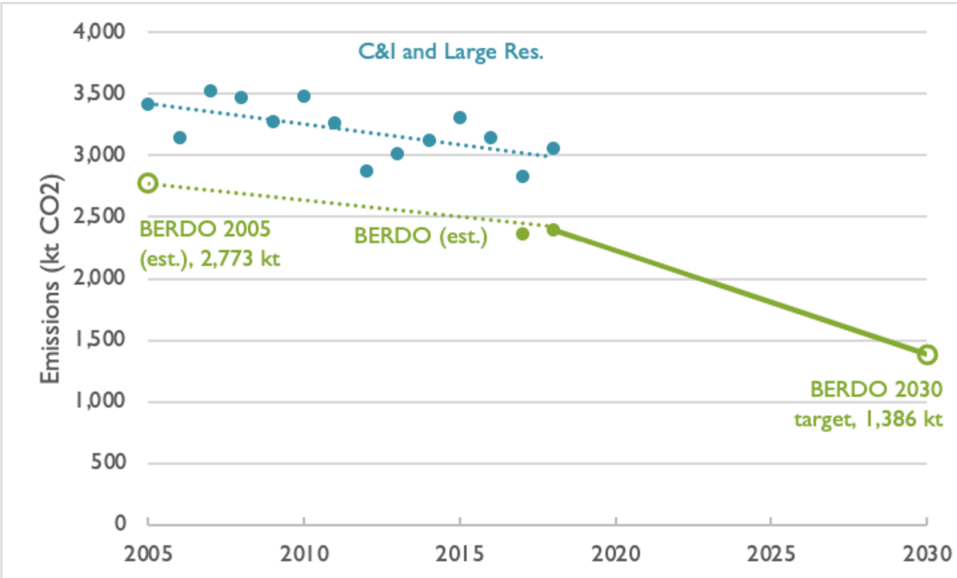
Synapse compiled the results of the TAG review of these various policy design dimensions and shared them with the City of Boston and TAG through a series of poll summaries, meeting notes, and presentations. The City will use these results alongside stakeholder input to develop a final policy.

2.5. Performance standard targets

A primary outcome of the technical advisory process was to help develop and recommend emission targets that decrease over time to ensure that the covered buildings achieve reductions consistent with the City of Boston's climate targets. One of the policy approaches that the TAG suggested for evaluation is to create fixed emission thresholds (e.g., kilograms of carbon dioxide equivalent per square foot of building area) by typology that decrease over time.

Synapse, in conjunction with the TAG, developed proposed emission thresholds for each building typology. To align with Boston's climate goals, the targets need to ensure that relative to 2005 emission levels, regulated buildings overall achieve a 50 percent reduction in emissions by 2030 and a 100 reduction by 2050. We used historical data back to 2005—GHG emissions inventory data provided by the City, weather data, and ISO-NE emissions factors—and recent years' BERDO data to estimate the 2005 emissions for BERDO-regulated buildings, which we used to derive the total emissions allowable under the policy in Year 2030. Figure 6 depicts this analysis.

Figure 6. Emissions from BERDO buildings, historical estimate and 2030 target



Source: Synapse model using BERDO and City of Boston GHG emissions inventory data. Blue data points represent all commercial, industrial, and large residential buildings. Blue dotted line is a regression analysis of historical data. Green data points represent only the building currently covered by BERDO (e.g., based on size threshold). Green dotted line is an extrapolation of historical BERDO emissions data to 2005 assuming the trend in BERDO building emissions corresponds to the trend seen for all commercial, industrial, and large residential buildings. Hollow green data points indicate the 2005 historical estimate and the 2030 target for all buildings covered by BERDO.

Next, we modeled the emissions associated with the BERDO building stock, including an estimate of emissions through Year 2050 assuming electricity grid emissions decline in conjunction with the Massachusetts Clean Energy Standard and other portfolio standard goals established across states within ISO-NE. With Synapse's building energy and emissions performance model, we compare portfolio-wide emissions against the City's climate targets under a range of fixed thresholds per typology. We use an optimization function to select the precise thresholds that will deliver in per-typology reductions that result in aggregate emission aligned with the city's targets, assuming every building currently above the threshold minimally complies with the policy. We allow reductions in building emissions due to increased supply of clean electricity to count toward achieving the city targets. The resulting emission thresholds are listed in Table 3.

Table 3. Building emission performance standard thresholds, without individual compliance schedule

Building typology	Emission standards ($kgCO_2e/SF$)					
Year	2025–2029	2030–2034	2035–2039	2040–2044	2045–2049	2050–
Assembly	8.3	5.4	3.7	2.4	1.2	0.0
College/University	12.1	6.3	4.3	2.8	1.4	0.0
Education	4.1	2.8	2.0	1.3	0.7	0.0
Food Sales & Service	18.8	12.3	9.0	6.0	3.0	0.0
Healthcare	16.2	11.3	8.3	5.5	2.7	0.0
Lodging	6.2	4.2	3.1	2.0	1.0	0.0
Manufacturing/Industrial	25.0	17.6	12.6	7.6	3.6	0.0
Multifamily housing	4.4	2.8	2.0	1.3	0.6	0.0
Office	5.9	3.7	2.7	1.8	0.9	0.0
Retail	8.4	4.0	2.8	1.7	0.8	0.0
Services	8.4	5.1	3.7	2.5	1.2	0.0
Storage	6.0	3.5	2.3	1.2	0.5	0.0
Technology/Science	20.7	13.1	9.0	5.7	2.8	0.0

Source: Synapse model using BERDO data and historical Boston GHG emission inventories.

Alternate targets with option for individual compliance schedules

An additional policy approach that the TAG considered is to allow building owners to have individual compliance schedules that demonstrate declining emissions, such as on a linear basis or quicker (*e.g.,* relative to a baseline year, a percent reduction that increases over time), in alignment with the City's climate goals. To ensure that this policy design did not penalize buildings that already have low emissions intensities (and therefore may have limited ability to achieve percentage-based emission reductions in the near term) the TAG recommended allowing building owners to choose between a threshold-based standard and an individual compliance path. Synapse recalculated the performance standard thresholds needed to achieve Boston's climate goals if each building owner citywide selected the compliance approach that was comparatively less stringent on a per-building basis (*i.e.,* poor-performing buildings follow individual compliance schedules and high-performing buildings follow threshold standards). The resulting thresholds are shown in Table 4, with the individual compliance schedules in Table 5.

Table 4. Building emission performance standard thresholds, with individual compliance schedule

Building typology	Emission standards ($kgCO_2e/SF$)					
Year	2025–2029	2030–2034	2035–2039	2040–2044	2045–2049	2050–
Assembly	7.8	4.6	3.3	2.1	1.1	0.0
College/University	10.2	5.3	3.8	2.5	1.2	0.0
Education	3.9	2.4	1.8	1.2	0.6	0.0
Food Sales & Service	17.4	10.9	8.0	5.4	2.7	0.0
Healthcare	15.4	10.0	7.4	4.9	2.4	0.0
Lodging	5.8	3.7	2.7	1.8	0.9	0.0
Manufacturing/Industrial	23.9	15.3	10.9	6.7	3.2	0.0
Multifamily housing	4.1	2.4	1.8	1.1	0.6	0.0
Office	5.3	3.2	2.4	1.6	0.8	0.0
Retail	7.1	3.4	2.4	1.5	0.7	0.0
Services	7.5	4.5	3.3	2.2	1.1	0.0
Storage	5.4	2.8	1.8	1.0	0.4	0.0
Technology/Science	19.2	11.1	7.8	5.1	2.5	0.0

Source: Synapse model using BERDO data and historical Boston GHG emission inventories.

Table 5. Individual compliance schedule

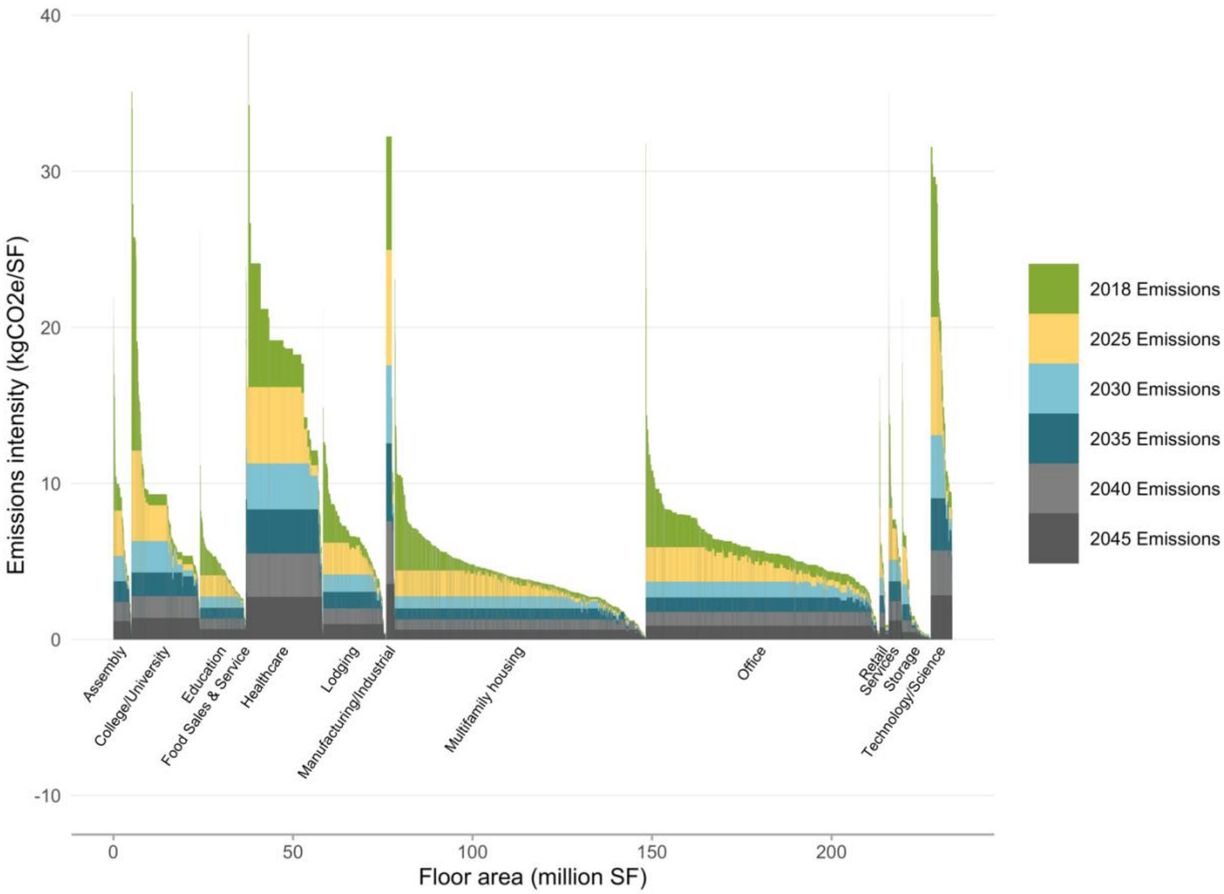
Emission target relative to 2018 baseline	
2025	76%
2030	52%
2035	39%
2040	26%
2045	13%
2050	0%

Source: Synapse model using BERDO data and historical Boston GHG emission inventories

2.6. Policy impact on emissions over time

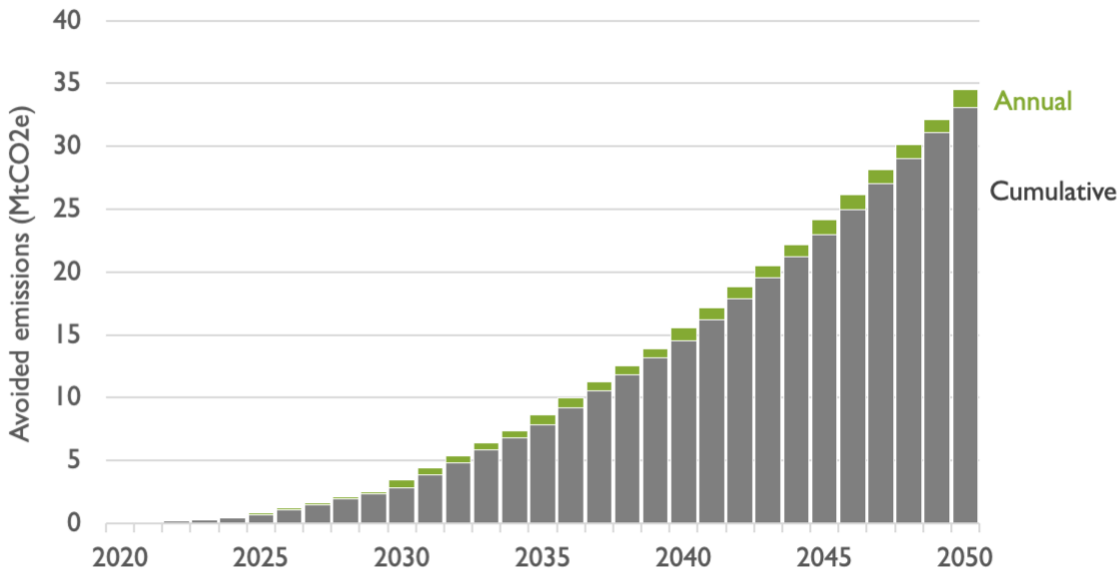
Synapse quantified the total effect of the policy within the context of an electricity grid which uses increasingly more clean energy sources over time. We modeled the emissions of each building over time under the policy scenarios described in Section 2.5 above, using a decision model that assumes each building minimally complies with the policy. Figure 7 shows the resulting emissions across all regulated building for each policy milestone year. Next, we aggregate the annual and cumulative emission reductions to determine the total impact, as depicted in Figure 8.

Figure 7. Building emissions intensity over time with performance standard



Source: Synapse model using BERDO data. Individual buildings (n = 1502) are plotted as vertical bars with width proportionate to gross floor area and height proportionate to emission intensity.

Figure 8. Building performance standard policy impact with increasing clean energy grid resources



Source: Synapse model.

3. Building Decarbonization Pathways

Boston's emission performance standard will require that covered buildings achieve net-zero carbon emissions by Year 2050, but it will not prescribe *how* buildings must meet that target. Building owners—likely with the assistance of energy assessors, engineers, and other building science experts—will need to identify the best approach to reducing their emissions across a range of strategies. Owners will be faced with important tradeoffs between the costs and benefits of the available technologies and techniques. While each building's pathway to decarbonization may be different, every building will need to accomplish some combination of the following approaches to reducing emissions: (1) retrofitting buildings to be more energy efficient and reduce overall energy use, (2) eliminating the use of fuels that cause GHG emissions (*e.g.,* combustion of fossil fuels), and (3) producing or purchasing clean energy to power building operations. In this section we summarize the approach that Synapse and the TAG used to identify net-zero carbon performance pathways for the regulated buildings and quantify the associated costs.

3.1. End-use energy, emissions, and equipment profiles by typology

Energy is used in buildings to provide key services such as lighting, appliances, space heating, space cooling, ventilation, water heating, and power to other equipment and devices. To understand the opportunities for reducing emissions from buildings first requires quantifying the amount of energy by fuel type used to provide the building services. The BERDO dataset does not include detailed characteristics, end-use energy, or equipment data, so Synapse developed estimated profiles for each typology using other data sources.

Synapse's building energy and emissions performance model generates end-use energy, building characteristic, and equipment summaries for a city's building stock using detailed building data from a range of sources. For this analysis we included a range of information from nationwide databases to Massachusetts building surveys and local energy audits, technical reports, and building records.[13] We filtered the master dataset to reflect the BERDO buildings, for example, isolating commercial buildings 35,000 square feet or greater and excluding buildings from other geographic regions. Next, we generated representative energy use profiles by end-use[14] for each typology by (1) calculating the average energy intensity by end-use for the survey building data, (2) initially assuming an equivalent end-use breakdown for the BERDO buildings, (3) calibrating the end-use breakdown to the total BERDO energy use, and (4) apportioning the BERDO fuel use across the relevant end-uses.[15] To estimate end-use emissions, we aggregated the emissions for each fuel that contributed to the end-use energy (using the fuel-specific emission factors noted in Section 2.3). Figure 9 provides an example of the results of this analysis—estimated end-use emission profiles for each building typology and all BERDO buildings in aggregate.

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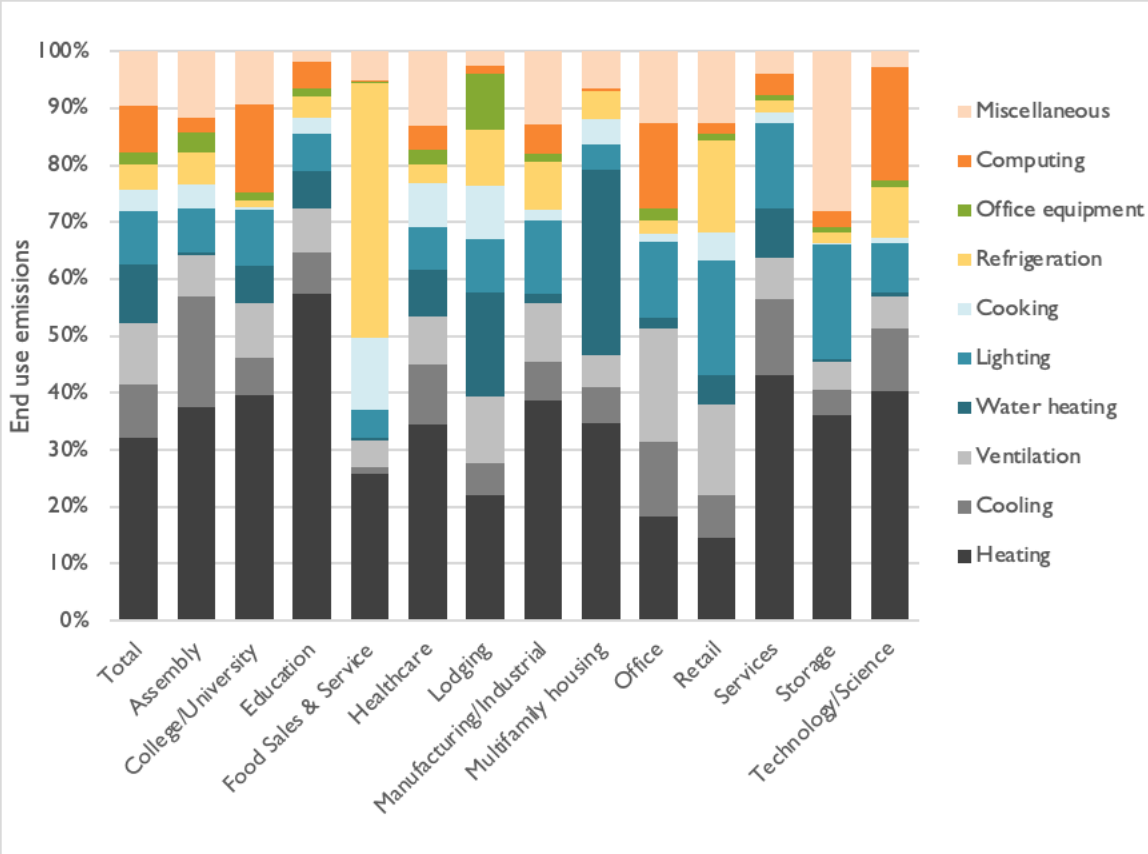
[13] Sources of detailed building energy and equipment data used in this study include:

A. City of Boston, Assessing Department. 2019. *Property Tax Assessment Database, 2019*.
B. City of Boston, Environment Department. 2019. *Building Energy Rating and Disclosure Ordinance (BERDO), Reported Energy and Water Metrics, 2019*.
C. DNV GL. 2016. *Massachusetts C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study*. Massachusetts Program Administrators Research Team and Energy Efficiency Advisory Council EM&V Consultants.
D. The Cadmus Group, Inc., Energy Services Division Navigant Consulting, Opinion Dynamics Corporation, Itron, ERS, 2012. *Massachusetts Multifamily Market Characterization and Potential Study Volume 1*.
E. U.S. Energy Information Administration (EIA). 2013. *Commercial Buildings Energy Consumption Survey (CBECS), 2012*.
F. U.S. EIA. 2018. *Residential Energy Consumption Survey (RECS), 2015*.
G. Hatchadorian, R., Best, R., Wholey, K., Calven, A., Levine, E., Tepfer, S., Swett, B., Walsh, M.J., Pollack, A., Perez, T., Castigliego, J.R., and Cleveland, C.J., 2019. *Carbon Free Boston: Buildings Technical Report.* Boston University Institute for Sustainable Energy. Available at http://sites.bu.edu/cfb/technical-reports.
H. ASHRAE Level II energy audits prepared for BERDO compliance.

[14] We divide energy use into 10 end-uses: heating, cooling, ventilation, water heating, lighting, cooking, refrigeration, office equipment, computing, and miscellaneous.

[15] As an example of step four, natural gas is divided among heating, cooling (*e.g.,* via adsorption chillers), water heating, and cooking.

Figure 9. Emissions profiles in BERDO buildings by end-use and building typology



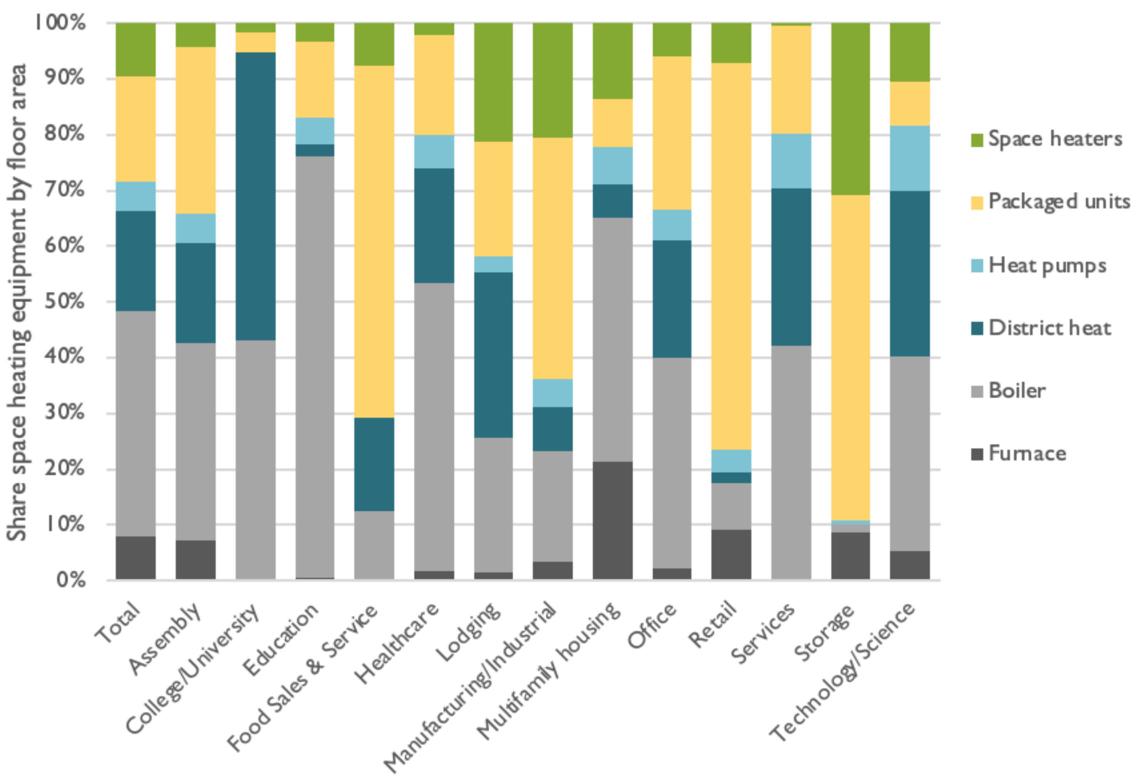
Source: Synapse model using BERDO data and national, state, and local building survey results.

We used a similar approach to develop end-use equipment and building characteristic summaries for the BERDO building stock. Using the same filtered dataset to reflect the BERDO buildings, we generated representative equipment profiles and building characteristic summaries for each typology by summarizing the master dataset, assuming equivalent distribution for the BERDO buildings, and apportioning the equipment information and building characteristics according to the known fuel-use breakdown in the BERDO dataset.[16] The distribution of heating equipment across each building typology and all BERDO buildings in aggregate is summarized in Figure 10. See the supplemental materials for additional building characteristic summaries, including the following:

[16] As an example of the final step, heating equipment is assigned according to the end-use heating fuels: within a typology, electrical heating equipment (e.g., heat pumps, resistive coils in packaged units, and individual space heaters) is assigned across the percent of buildings that use natural gas for heating in proportion to the breakdown of electrical heating equipment in the survey data.

- Space cooling equipment types
- Lighting technologies
- HVAC controls
- Lighting controls
- Construction type
- Window types
- Historic buildings
- Roof material
- Roof tilt
- Cool roof
- Insulation upgrades
- Computers
- Refrigeration equipment

Figure 10. BERDO space heating equipment characterization by building typology



Source: Synapse model using BERDO data and national, state, and local building survey results.

3.2. Decarbonization strategies

Synapse and the TAG identified a series of emission abatement[17] strategies appropriate to the stock of regulated buildings, including retrofitting buildings to be more energy efficient, eliminating the use of fuels that cause GHG emissions, and producing or purchasing clean energy. For each strategy we quantified the potential energy and emissions savings associated with implementation across the stock of regulated building, and then estimate the lifecycles costs and savings.

[17] Abatement of emissions is the reduction of GHG emissions from energy systems and other processes.

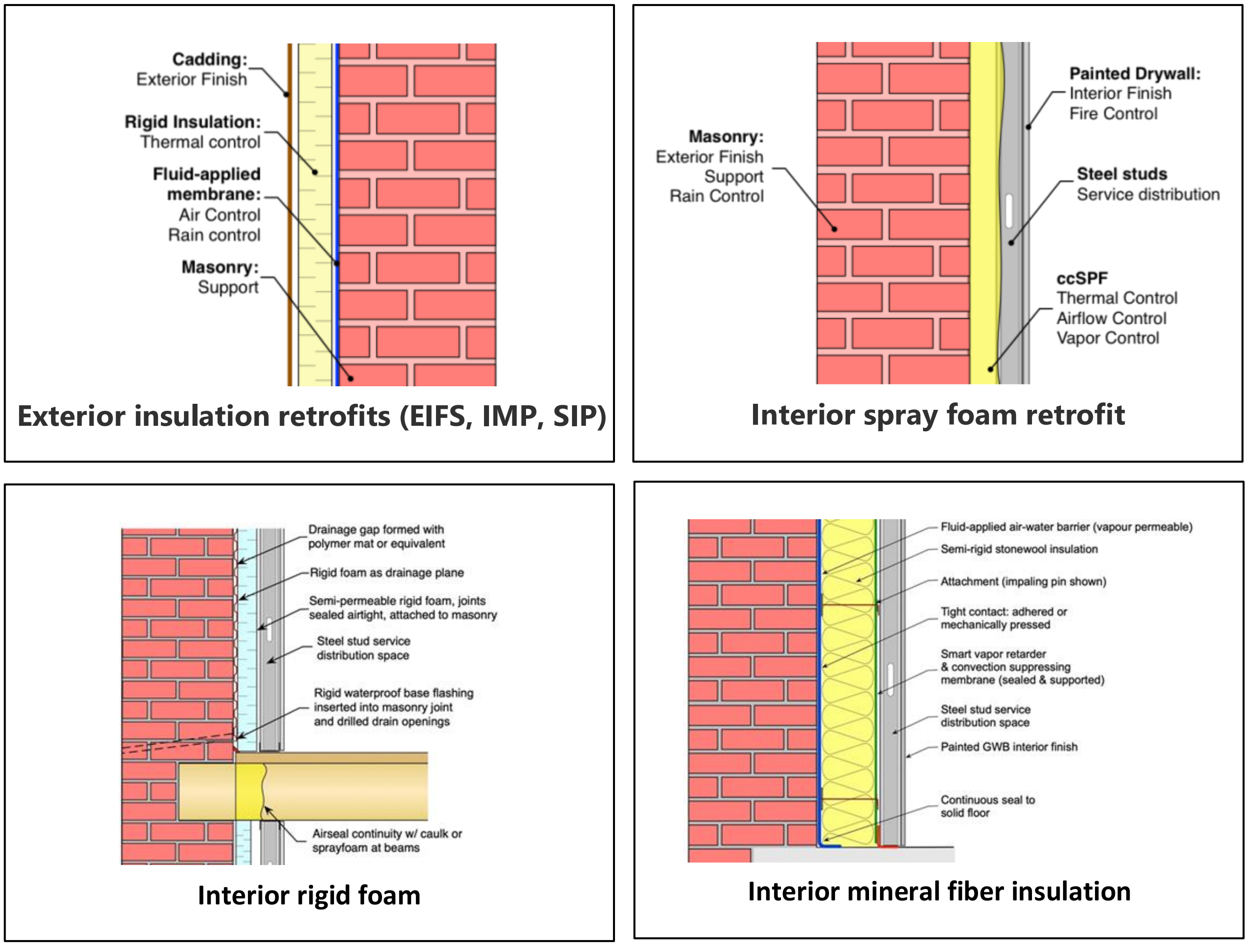
Energy and emissions modeling

We conducted energy modeling of the end-use building systems in order to estimate the possible contribution of each strategy toward achieving net-zero carbon in the regulated building stock. The results of the analysis described in Section 3.1 above form the foundation for this work by identifying the end-use energy, emissions, and equipment across the 13 identified typologies. Table 6 summarizes retrofit measures and abatement strategies applicable to the existing equipment and systems. The strategies we evaluate are customized to the Boston climate; for example, Figure 11 identifies cold climate insulation and moisture control strategies appropriate for masonry and cast walls (brick, stone, stucco, concrete block, concrete poured, concrete panel), which are the dominant construction types in the regulated buildings in Boston.

Table 6. Decarbonization strategies evaluated for Boston's building emissions performance standard

System	Strategy
Envelope	• Air seal exterior penetrations • Add insulation to walls and roof • Window replacement and storm windows
Electrification of energy end-uses and supply	• Heating electrification: boiler to heat pump • Heating electrification: furnace to heat pump • Cooling electrification: absorption chiller to electric chiller • Water heating electrification: natural gas to heat pump • Cooking electrification: ovens, griddles, fryers • District energy system electrification: absorption chiller to heat recovery electric chiller • District energy system electrification: boilers and co-gen heat recovery to heat pumps
Heating, ventilation, air-conditioning, and refrigeration	• Cooling system replacement: heat pump • Mini split heat pump conversion: individual room A/C • Heat pump conversion: electric resistive heater • Comprehensive HVAC controls and retuning measures • Enhanced energy recovery ventilation • Convert constant air volume to variable air volume • Demand controlled ventilation • Refrigeration retrofits and controls
Lighting	• LED lighting conversion • Lighting controls: occupancy sensors, daylight dimming, timers
Water heating	• Heat pump water heater conversion: resistive water heater • Water conservation retrofits
Plug loads, process loads, and miscellaneous loads	• IT and process load energy management • Smart strip for plug load control
Renewable energy	• On-site solar photovoltaic • Off-site renewable energy purchase

Figure 11. Cold climate insulation and moisture control strategies for masonry and cast walls



Figures provided courtesy of buildingscience.com.
Source: Building Science Corporation. 2007. BSD-114: Interior Insulation Retrofits of Load-Bearing Masonry Walls In Cold Climates. Available at: https://www.buildingscience.com/documents/digests/bsd-114-interior-insulation-retrofits-of-load-bearing-masonry-walls-in-cold-climates.

To quantify the opportunity to reduce energy use and emissions, we first developed a model of the existing energy usage in the BERDO buildings. We used a range of building science and industry data[18] to estimate the performance of the existing equipment and systems in Boston buildings. Combining end-use energy information with equipment and building performance data, we derived the quantities of useful, energy-based building services: lighting, heating, cooling, ventilation, water heating, etc. Next,

[18] A full list of data sources for equipment and system performance is provided in the supplemental materials and includes the following reference types: building equipment standards and databases maintained by federal agencies and laboratories (*e.g.,* U.S. Department of Energy, U.S. EIA, Lawrence Berkley National Lab, National Renewable Energy Lab, Pacific Northwest National Lab, Oak Ridge National Lab); manufacturer equipment data; state technical reference manuals for estimating energy savings from energy efficiency measures; the International Energy Conservation Codes; standards promulgated by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers; equipment databases maintained by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI); and other literature search.

we used building science and industry data (see footnote 18) to identify the potential future performance of equipment and systems if the decarbonization strategies are adopted. Comparing the before and after energy flows by fuel type allows us to quantify the energy and emission savings of each strategy. Where relevant, we model the impact of local weather conditions on the equipment system performance. This effect is most important for air-source heat pumps, for which performance declines in cold weather. We evaluated system performance in Boston for three common air-source heat pump system configurations[19] over the course of a year, using published temperature-variant equipment performance data and hourly typical meteorological year weather data for the Boston area.

Decarbonization strategy lifecycle cost modeling

Synapse and the TAG quantified the cost of implementation and the associated energy savings for the decarbonization strategies from the perspective of the regulated building.[20] We identified sources of cost data for each of the abatement strategies—initial capital investment and ongoing operation and maintenance costs, where applicable and substantially different than the existing system—prioritizing local data.[21] Figure 12 shows an example of the cost data used in the model, in this case, for insulation and moisture control systems in Boston. We compute present value costs and savings for the proposed strategies as the difference between the lifecycle costs of the proposed systems and the existing ones. For example, converting a natural gas furnace to an electric heat pump for space heating will incur an initial capital investment,[22] increase electricity costs, and decrease natural gas costs relative to the existing equipment; we aggregate the costs and the savings over the useful life of the heat pump (*e.g.,* 15 years) relative to the natural gas furnace.

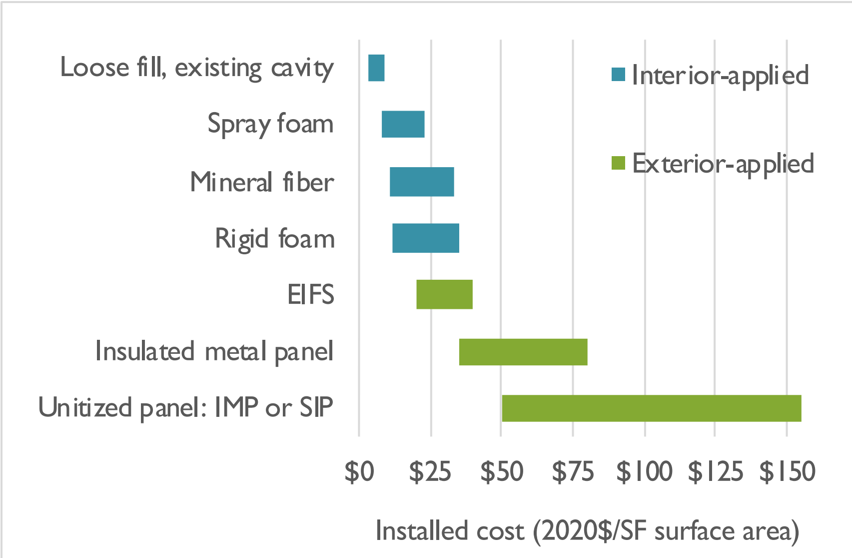
[19] We included variable refrigerant flow (VRF), ductless mini-split, and ducted systems in our analysis.

[20] This study does not attempt to estimate costs and benefits from the perspective of the utility grid or society.

[21] A full list of data sources for equipment and system cost is provided in the supplemental materials and includes the following reference types: technical reports from local and state building policy analysis (*e.g., Carbon Free Boston*); energy efficiency program administrator databases; local case studies; local construction data; building cost databases maintained by federal agencies, laboratories, and research institutions; and other literature search.

[22] Refer to Section Appendix A for a discussion of total cost compared to incremental costs.

Figure 12. Typical commercial and multifamily insulation costs in Boston



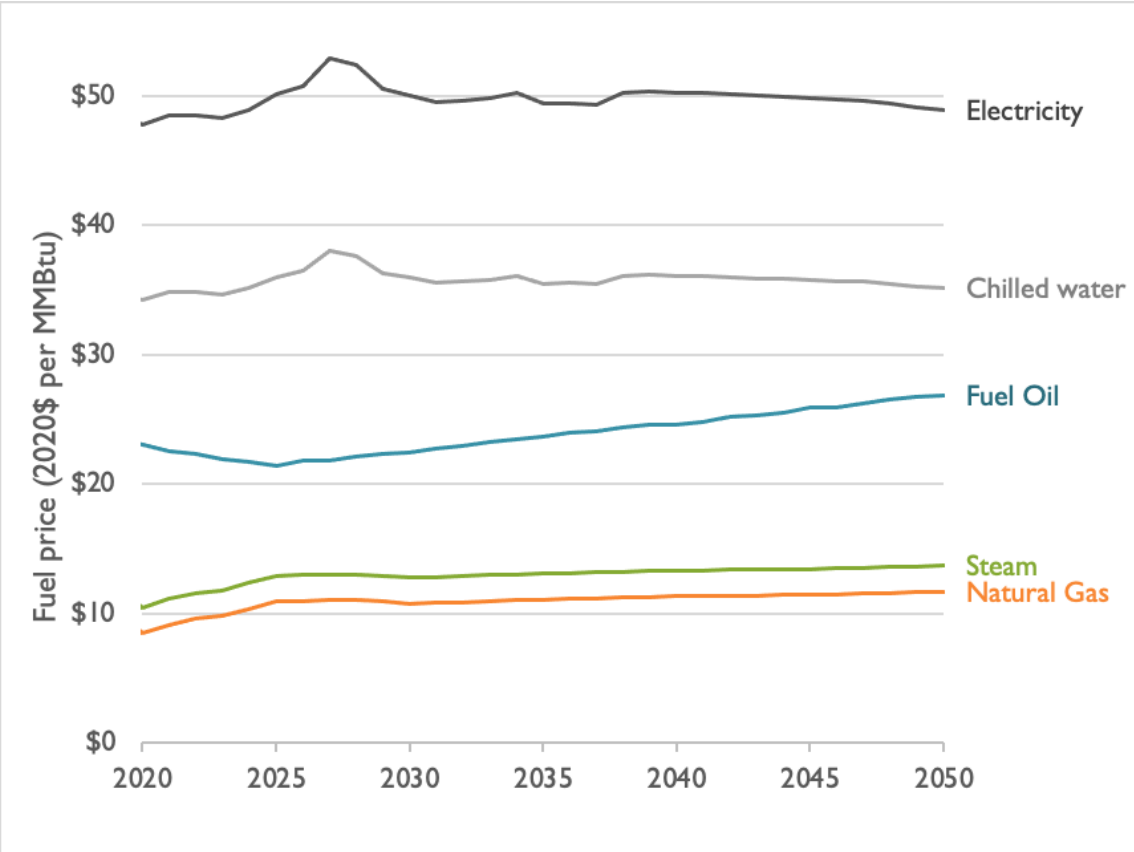
Source: Synapse model, including data from Turner Construction, MassSave Energy Efficiency Program Administrator databases, WinnCompanies case studies, Carbon Free Boston, Rocky Mountain Institute. Includes cost of materials and labor. Abbreviations: exterior insulation and finish system, insulated metal panel, structurally insulated panel.

Our analysis quantifies present values of costs and benefits for commercial buildings across the identified typologies and publicly owned buildings in real dollars (*i.e.,* adjusted for inflation) using an appropriate discount rate to the regulated sectors.[23] We assume equipment systems useful life based upon the *Massachusetts Technical Reference Manual*.[24] The fuel price forecast in our model, shown in Figure 13, is based on the U.S. Energy Information Administration's 2020 Annual Energy Outlook and local district thermal system tariffs. Our forecast is in real dollars (*i.e.,* adjusted for inflation) and assumes the prices of steam and chilled water are correlated with the prices of natural gas and electricity, respectively.

[23] A 2020 study by Lawrence Berkley National Laboratory provides mean weighted average cost of capital detail: Fujita, K., 2020. *Commercial, Industrial, and Institutional Discount Rate Estimation for Efficiency Standards Analysis: Sector-Level Data 1998–2018*. Lawrence Berkeley National Lab.

[24] Massachusetts Electric and Gas Energy Efficiency Program Administrators, 2018. *Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2019-2021 Plan Version*.

Figure 13. Energy price forecast in real (inflation adjusted) dollars



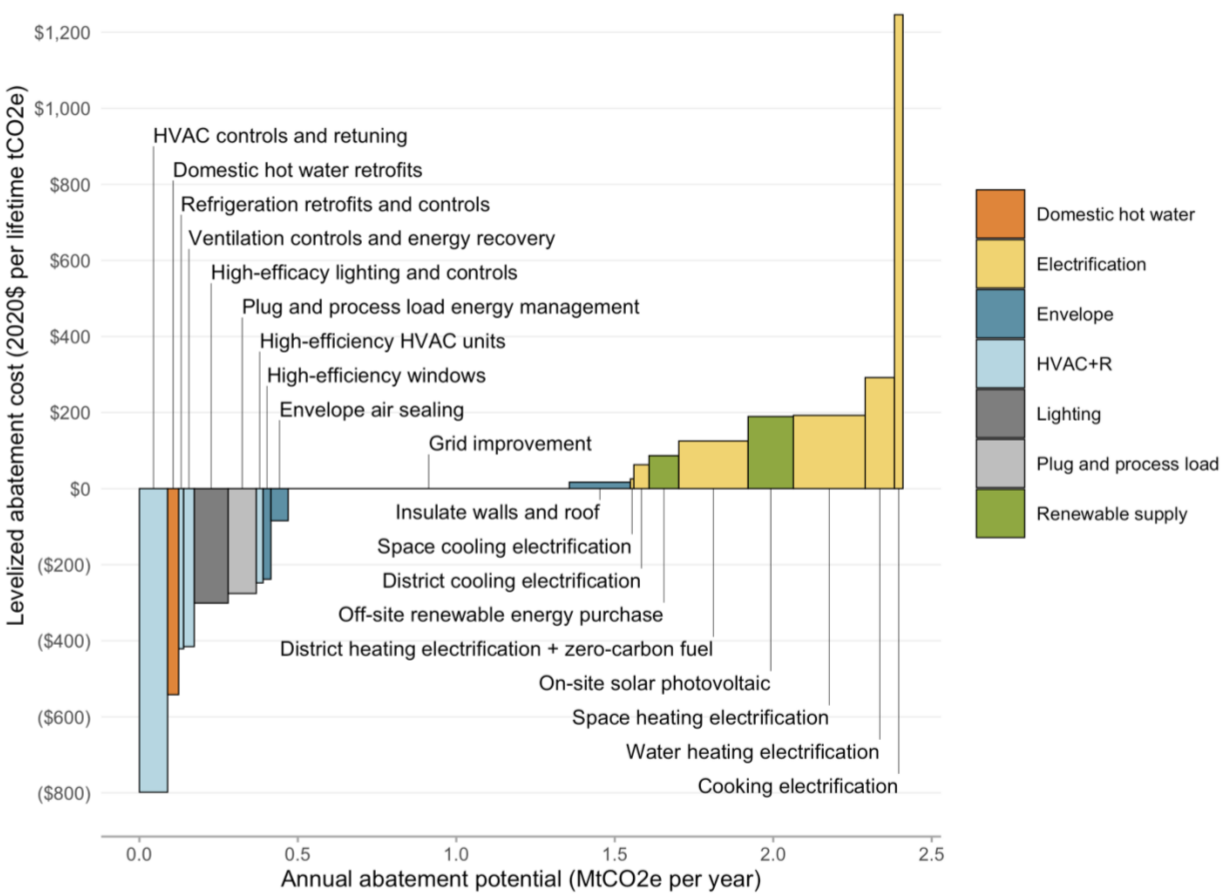
Source: Synapse model with data from U.S. EIA 2020 Annual Energy Outlook and local district energy system tariffs.

3.3. Pathways to net-zero carbon and levelized cost of abatement

To cost-effectively advance the portfolio of large buildings in Boston toward net-zero carbon by 2050 requires comparing emissions reductions and costs across abatement strategies and mapping holistic pathways that take advantage of lower-cost, high-return upgrades. However, existing buildings will need to move beyond standard low-cost energy efficiency retrofits to realize deep emissions reductions. Achieving net-zero carbon will require a comprehensive approach including retrofitting the existing building structure, upgrading equipment systems at the time of replacement, switching away from fossil-based fuels (*e.g.,* electrifying end-uses of energy that rely on combustion of fossil fuels), and procuring or installing renewable energy sources. This holistic "pathway" will vary across individual buildings and typologies based upon the buildings' characteristics, existing fuel sources, and end-use equipment.

We first estimated on equal terms the levelized cost of emission reductions across all building-level actions. This provides insight into the total amount of GHG emissions buildings can reduce for a given dollar investment across all buildings subject to the building performance standard. Building owners will need to weigh different priorities to ensure that they achieve the performance standard targets at lowest cost. We estimated the levelized cost of GHG abatement in dollars per lifetime metric ton of carbon dioxide equivalent for each strategy, taking the difference in present value costs between the proposed system and the existing system and dividing by the difference in lifetime emissions. Note that the emission reduction potential for a given strategy will vary with time if the emissions factor is not constant. Figure 14 presents the results of this analysis for all strategies assuming a 2035 electricity grid emissions factor, with results ordered from least-to-greatest net abatement cost. The supplemental materials provide the results using alternate electricity grid emission factors for years 2025 and 2050.

Figure 14. Levelized abatement cost of building decarbonization strategies, 2035 grid emission factor



Source: Synapse model.

The Boston decarbonization pathways include a comprehensive package of energy efficiency measures at all properties. Due to the substantial portion of energy and emissions attributed to space heating, all of the retrofit paths include upgrades to the building envelope and major improvements and fuel switching (*e.g.,* electrification) for fossil-based heating equipment, aimed at reducing heating loads and adopting technologies that can operate on a clean energy supply. Decarbonization of district heating and increased renewable energy supply are necessary to eliminate remaining emissions from thermal loads and the electricity sector, which is currently on trajectory for 80 percent decarbonization by 2050.

Finally, we estimated the average levelized abatement cost across the breadth of strategies included in the decarbonization pathways, aggregating the cumulative implementation costs and dividing by the total emissions abated. The average levelized abatement cost for the strategies we evaluated ranged from $211 to $234 per ton of carbon dioxide equivalent, with variation in cost due the potential for differing grid emission factors at the time the strategies are implemented.

3.4. Low-carbon district thermal system case studies

District heating and cooling accounted for nearly 20 percent of the energy use and emissions in BERDO buildings in 2018. Decarbonizing existing district thermal systems in the greater Boston area will be a difficult, yet critical aspect for achieving net-zero carbon by 2050. Synapse prepared case studies to support the TAG evaluation of decarbonization pathways for buildings that utilize district thermal resources. The case studies indicate that conversion of existing fossil-based steam systems to heat pump hot water systems is likely to be highly capital intensive, yet effective at reducing emissions in an otherwise hard-to-decarbonize system. Table 7 summarizes low-carbon district heating systems in cold-climate countries and one system in the United States, demonstrating a range of strategies for capturing waste heat and ambient heat. Many of the same heat sources are available in Boston. These systems range in capacity and illustrate the potential for scalability. Combustion-based systems achieve less than 100 percent thermal efficiency, whereas these heat pump systems have coefficients of performance ranging from 2.0 to 7.9 and therefore provide between 200 and 790 percent as much heat as the energy they consume.

Table 7. Low-carbon district heating system case studies

Case Study	Country	HP (MW)	COP	Heat source temp	Heat source	DH network Customers	Heat type	Source
Pump manufacture Grundfos in Bjerringbro: Synergies between industry and district heating	Denmark	3.7	4.6	40°C	Excess heat from cooling	2271 consumers		[1]
Skjern Papirfabrik: Heat recovery from local paper mill	Denmark	3 x 1.33 MW HP	6.9	43°C	Low-temperature heat from the production process			[1]
Rødkærsbro Fjernvarmeværk: Industrial wastewater used for district heating	Denmark	1.6	4.6	22-25°C	Low temperature industrial wastewater	600 consumers		[1]
Tønder: Co-production with a gas engine driven heat pump	Denmark	4.3 MW gas and 3.3 MW electric	2.16 using air and 2.9 using excess heat	20°C	Process cooling and air			[1]
Regional hospital in Viborg: heat recovery chillers	Denmark	2.5	7.9	43C	Excess heat from chillers			[1]
Glostrup Varme: Excess heat from mink coat storage	Denmark	1	5	70-90°C	Industrial excess heat from cooling			[1]
The City of Bergheim: Excess heat from lignite mining in Bergheim, Germany	Germany	0.87 MW HP and 0.3 MW CHP	3	27°C	Excess heat from open pit mining			[1]
The City of Mäntsälä: Datacentre supplies local heating	Finland	4	4	40°C	Cooling of data center	1,500 homes		[1]
The city of Gothenburg: Heat pumps using wastewater	Sweden	160	3	12°C	Wastewater		Hot water	[1]
Høje Taastrup Fjernvarme: Excess heat from vegetable market	Denmark	2.3 MW heating 2 MW cooling	3.14 heating, 2.16 cooling	16°C	Heat from district cooling	6,784 consumers	Hot water	[1]
Warmtelevering Leidse Regio project: Industrial residual heat and transmission in Leiden, Netherlands	Netherlands				High-temperature transmission and low-temperature return flow from industrial residual heat	13,000 households, 200 companies		[1]
Mänttä-Vilppula district heating: A steam-temperature heat pump supplies temperatures of up to 120°C	Finland	0.158	2.0 at the highest flow	45-55°C	Return line of the district heating system		Steam (70-120°C)	[2]

Case Study	Country	HP (MW)	COP	Heat source temp	Heat source	DH network Customers	Heat type	Source
Swiss Krono factory: Heat pumps boosting the energy efficiency chipboard factory	Germany	10					Hot water (80°C)	[2]
Budapest military hospital: Wastewater used for heat and cooling	Hungary	3.8	6.8		Wastewater in the sewage system			[2]
Oslo district heating: Sea water heat pump for district system in Fornebu/Rolfsbukta	Norway	16	4.4		Sea water		Hot water (75°C)	[2]
Stanford University: Central Energy Facility with PV, heat recovery plant, thermal storage	United States	100			Heat recovery chillers	155 buildings	Hot water	[3]

[1] Petersen, A. 2017. Handbook: Experiences from other urban waste heat recovery investments. Reuse Heat and GrønEnergi.
[2] Thomas Nowak. Large-scale heat pumps in Europe. European Heat Pump Association.
[3] Patel, N.R., M.J. Risbeck, J.B. Rawlings, C.T. Maravelias, M.J. Wenzel, and R.D. Turney. 2018. "A case study of economic optimization of HVAC systems based on the Stanford University campus airside and waterside systems." International High Performance Buildings Conference. Paper 253.

Appendix A. SCENARIOS AND SENSITIVITIES

There are uncertainties and limitations to Synapse's estimated costs and impacts of a building performance standard in Boston. With a policy horizon three decades in the future, the predictive capabilities of any model are challenged by emerging and evolving technologies, a changing policy landscape, energy price volatility, changing technology costs, and more. The results of this study identify likely emission targets and costs to achieve decarbonization by the year 2050. We recommend these outcomes be reevaluated periodically with updated inputs.

To identify plausible bounds to the uncertainty in this analysis, Synapse and the TAG identified a range of potential scenarios and sensitivities to evaluate in our model.

- **Policy scenarios**: We prepared three sets of emission targets, associated with differing policy designs—(1) a threshold-only emission performance standard in kilograms of carbon dioxide equivalent per square foot specific to each typology, (2) an individual compliance schedule in which all buildings must meet percentage reductions in emissions, and (3) a performance standard that provides building owners the choice between threshold-based targets or individual compliance schedules. We designed the performance standard targets in each scenario to deliver the same emission savings (a) in aggregate across each typology and (b) over time to align with the City of Boston's climate targets. However, the policy scenarios resulted in substantial differences in the timing of emissions reductions required on a building-by-building basis within each typology. The threshold-only approach required comparatively greater reductions from poor performing buildings early in the policy implementation period. Individual compliance schedules with percentage reductions required high-performing buildings to make reductions comparatively sooner than in the threshold-only scenario. The third policy option—in which building owners choose between threshold-based targets or individual compliance schedules—requires slightly more stringent thresholds to make up for the smaller reductions from poor-performing buildings early in the implementation period.

- **Emission factors**: we examined the impact of changing electricity grid emission factors on emission savings and cost. For each abatement strategy, we advanced the emission factor in 5-years increments toward the state's 2050 target and observed the differing impact on energy efficiency and fuel-switching measures, as well as the effect on total decarbonization cost.

- **Equipment replacement**: where applicable, we considered the cost impact of different timing or sequencing of decarbonization measures. We identified three possible approaches, "retrofit immediately," "retrofit at occupant turnover," and "replace at building system end of life." Under the third approach, we assumed the cost of implementation is only the incremental cost of the measure above a like-for-like replacement, whereas the first approach uses the full cost of the measure. The TAG recommended using a "retrofit immediately" approach for strategies that result in net cost savings over the life of the equipment, and a “replace at building system end of life” for capital intensive measures that do not generate net savings.

- **Building size threshold**: we identified the impact of a performance standard applied only to those buildings currently regulated under BERDO versus reducing the size threshold to 20,000 square feet. We estimated that reducing the building area threshold would increase the emission savings by 2.0 million metric tons of carbon dioxide equivalent—about 7 percent greater impact—through Year 2050. It would extend the administrative and compliance efforts to an additional 1,200 buildings or approximately 53 percent more buildings, representing an additional 38 million square feet.

Appendix B. GLOSSARY

Abatement of emissions is the reduction of greenhouse gas emissions from energy systems and other processes. Abatement of carbon emissions may be specifically referred to as **decarbonization** or **carbon abatement**.

Building Energy Reporting and Disclosure Ordinance (BERDO) is a 2013 regulation enacted by the City of Boston, which requires owners of large buildings to report their annual energy and water use to the City for public disclosure.

Carbon dioxide equivalent (CO_2e) is a unit of measurement that compares the effect of different greenhouse gases using carbon dioxide as a standard reference unit. Greenhouse gas emissions are commonly expressed in units of carbon dioxide equivalents: in kilograms (kg CO_2e), metric tons (t CO_2e), or million metric tons (Mt CO_2e). The carbon dioxide equivalent for a gas is derived by multiplying the tons of the gas by its associated global warming potential.

Carbon offset is a credit for greenhouse gas reductions that can be purchased and used to offset the greenhouse gas emissions. Offsets are typically measured in metric tons of carbon dioxide equivalent, and are bought and sold through international brokers, online retailers, and trading platforms. Common forms include investments in renewable energy, energy efficiency, and forestry.

Clean electricity is electricity produced from clean energy sources.

Clean energy is a group of energy sources that emit low-to-no greenhouse gas emissions. Clean energy includes nuclear power and carbon capture and storage in addition to renewables, such as solar, wind and biomass. Distinction between clean energy and renewables is often defined by statute.

Combined heat and power (CHP) is an energy conversion process in which more than one useful product (e.g., electricity and heat or steam) is generated from the same energy input stream. It is also referred to as **co-generation**.

Decarbonization is the reduction of carbon from energy supply chains and other processes. It is also referred to as **emissions abatement** or **carbon abatement**.

Emissions intensity is the amount of emissions of carbon dioxide released per unit of another variable, such as gross floor area, gross domestic product (GDP), output energy use, or transport. In this report we use emissions per square foot at a property to compare the emissions across differently sized buildings.

Emission factor is a value for scaling emissions to energy or activity data. Emission factors are commonly presented in terms of a standard rate of emissions per unit of energy or activity (*e.g.,* grams of carbon dioxide emitted per kilowatt-hour of electricity used).

Energy Star Portfolio Manager is a no-cost, web-based energy management tool developed by the U.S. Environmental Protection Agency and the U.S. Department of Energy that allows users to track and assess energy and water consumption across a portfolio of buildings.

Energy use intensity (EUI) is the energy use per square foot at a property. EUI is a common metric used to compare energy use across differently sized buildings.

Global warming potential (GWP) is an index measuring the radiative forcing resulting from an emission of a unit mass of a given substance, accumulated over a specified time horizon, relative to that of the reference substance, carbon dioxide (CO_2). The GWP thus represents the combined effect of the differing times these substances remain in the atmosphere and their effectiveness in causing radiative forcing.

Greenhouse gas (GHG) is a gas that absorbs infrared radiation in the atmosphere. Greenhouse gas emissions are commonly expressed in units of carbon dioxide equivalents: in kilograms (kg CO_2e), metric tons (t CO_2e), or million metric tons (Mt CO_2e).

Gross floor area (GFA) is the total square footage of a property. Properties may include single buildings or a campus of buildings. GFA is measured as the floor area between the outside surface of the exterior walls of the building(s). This includes all areas inside the building(s) including supporting areas.

- **Included in GFA:** lobbies, tenant areas, common areas, meeting rooms, break rooms, atriums (counting the base level only), restrooms, elevator shafts, stairwells, mechanical equipment areas, basements, and storage rooms.

- **Not included in GFA:** exterior spaces, balconies, patios, exterior loading docks, driveways, covered walkways, outdoor play courts (tennis, basketball, etc.), parking, the interstitial plenum space between floors (which house pipes and ventilation), crawl spaces.

ISO New England, Inc. is the independent, non-profit Regional Transmission Organization (RTO) serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

Metric ton (tonne) is an international measurement for quantities of greenhouse gas emissions. A metric ton is equal to 2,205 pounds or 1.1 short tons.

Renewable electricity is electricity generated from renewable energy sources.

Renewable energy is a group of energy sources that emit low-to-no direct greenhouse gases. Renewable energy is generated from renewable resources, such as solar, wind, geothermal, hydrokinetic energy, hydropower, and biomass. Distinction between clean energy and renewables is often defined by statute.

Renewable energy certificates (REC) are a market tradable commodity that represents proof that one megawatt-hour (MWh) of electricity was generated from a third-party-verified renewable energy resource, such as a solar renewable energy certificate (SREC) that is generated from solar energy resource. Also referred to as **renewable energy credits**.

Appendix C. ABBREVIATIONS

°C	Degrees Celsius
°F	Degrees Fahrenheit
BERDO	Building Energy Reporting and Disclosure Ordinance
BPDA	Boston Planning and Development Agency
BTU	British thermal unit
CCA	Community Choice Aggregation
CCE	Community Choice Electricity
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
ECM	Energy Conservation Measure
GFA	Gross floor area
GHG	Greenhouse gas
GWP	Global warming potential
ISO-NE	Independent System Operator of New England
PV	Photovoltaic
REC	Renewable energy certificate (or credit)
RNG	Renewable natural gas
t CO_2e	Metric ton (tonne) of CO_2e
TAG	Technical Advisory Group
W	Watt
Wh	Watt-hour