MassCEC BETA Commercial Buildings Pilot Market Characterization Report

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BACKGROUND AND APPROACH

ABOUT THIS REPORT

This report characterizes the population of multifamily and commercial buildings in Massachusetts to identify and prioritize key typologies to recruit for participation in the MassCEC BETA Commercial Buildings decarbonization pilot (the "Pilot"). Findings from this Pilot will support the creation of resources and will support broader market transformation activities to reach Massachusetts's 2050 greenhouse gas emission reduction goals for buildings. For this study, commercial buildings are defined to exclude industrial and manufacturing businesses.

Through analysis of public data sources and relevant market research reports, we identified key characteristics, such as primary building use, HVAC system, environmental justice indicators, size, and vintage. These characteristics can be used to distinguish building typologies which follow common decarbonization pathways that will be further developed through this Pilot. Similarly, we used key metrics, such as building counts, square footage, energy use and emissions to compare buildings with different characteristics in terms of their market share and their potential for scaled decarbonization impact.

This analysis informed the development of seven core typologies that are representative of the key decarbonization pathways for medium-to-large (i.e. >20,000 sq. ft.) commercial buildings in Massachusetts. These seven core typologies are placed in a framework for prioritizing participant selection to maximize the value of the initial cohort of 15 participating buildings to undergo decarbonization assessments in MassCEC's Pilot.

APPROACH

In this section we describe in detail our methods for conducting this market characterization and creating a framework to prioritize commercial building typologies for Pilot participation. The approach is organized around the following steps and guiding questions, which are described in more detail in the sections that follow:

1. **Develop value proposition framework to guide analysis and prioritization**: What are the key overarching value propositions to be used to identify, compare, and prioritize commercial building typologies?
2. **Identify primary characteristics to delineate typologies**: What building and ownership characteristics are most important for identifying buildings with common decarbonization pathways and obstacles?
3. **Identify key metrics for typology comparison and prioritization**: What metrics aligned with the value propositions can be used to compare and prioritize typologies?
4. **Analyze building stock data and review literature**: (1) Based on available data, what combinations of building characteristics form mutual typologies that align common decarbonization pathways? (2) How do these typologies compare by key metrics?

5. **Synthesize findings to create typology priority matrix:** (1) What core typologies emerge from patterns in the data and prior research? (2) How should they be prioritized for recruitment in the Pilot?

Value Proposition Framework

Because this market characterization is organized around a key outcome of creating a set of building typologies to prioritize for inclusion in the Pilot, we started by defining the core value propositions, which if fulfilled by the cohort of participating buildings, will collectively provide broad benefits and insights for ongoing building decarbonization in Massachusetts. Similarly, these value propositions guide the selection of key building characteristics and associated metrics to define and compare typologies in the market characterization analysis. Working with MassCEC and stakeholders, we identified these three value propositions for delineating and prioritizing building typologies which are also summarized in Figure 1.

High-impact scaling: some typologies will have characteristics which make scaling their decarbonization to the state-wide population easier and more impactful. Lessons learned from decarbonizing buildings in the most common building typologies like use types and HVAC systems, will naturally scale and apply broadly beyond this Pilot. Similarly, typologies with the highest site fossil fuel usage would have comparably greater scaled impacts. Policies targeting specific building typologies could make impacts from the Pilot scalable through access to grant funds or a need to meet existing electrification targets.

Environmental Justice: special consideration should be given to understanding unique challenges and opportunities associated with decarbonizing commercial buildings in designated environmental justice (EJ) communities. This will ensure that the results of this Pilot can apply to and benefit commercial businesses and multifamily residences owned, operated by, and/or serving vulnerable populations. Evaluating the applicability of environmental justice considerations for building types requires considering multiple sources of information about buildings and communities where they are located. These include EJ community designations based on state and national definitions, as well as, specific indicators related to income, ownership, and funding/maintenance mechanisms.

Applicability: to the extent possible, the building typologies identified in this report should have characteristics and associated decarbonization paths that represent most medium-to-large commercial buildings in the state. While the participating buildings selection process for the Pilot will include a weighting towards difficult to decarbonize building types, it is also important that participating buildings share features representative of this full universe of building typologies in the state. This means that the set of participating typologies should include a variety of HVAC systems, ages, sizes, ownership structures, financing mechanisms, and retrofit pathways so that lessons learned from this Pilot can apply broadly for informing future decarbonization efforts.

Findings from the market study are reviewed with a lens to inform the development of market resources which can support the commonwealth in scaling commercial building decarbonization. A key outcome is to develop a prioritization framework to conduct Pilot application selection by typology, building systems, and other factors. To guide these choices three main categories were developed that align with scaling impact, supporting environmental justice considerations, and having wide-ranging applicability. While many of the value propositions can be characterized within the available data sets used for this study, other areas for consideration denoted with an Asterix (*) in Figure 1 will be assessed at the time of application.

Figure 1. Prioritization value propositions for Pilot selection

High scaling impact

- -Common building types
- - High fossil fuel usage
- - Common HVAC types
- - Policy alignment:
  - - Benchmarking
  - - Full electrification*
  - - Existing resources*

Environmental Justice

- - Common building types in EJ communities
- - EJ designated by MA EEA*
- - EJ-specific challenges related to:
  - - Age of building
  - - Resource constraints*
  - - Maintainability
  - - Air quality

Applicability (breath/depth)

- - HVAC coverage of simple and complex systems
- - Coverage contains at once replacement /over time*
- - Range of typologies and ownership drivers
- - Covers range of ages
- - Covers range of systems and scenarios
- - Includes recent retrofits*

Building Characteristics, Metrics and Data Sources

Key building characteristics and associated metrics for qualitative comparison were identified to align with the value propositions, recent decarbonization research, staff expertise, and data availability as seen in Table 1. Characteristics like use type, size, vintage and HVAC/DHW types intersect to define typologies with a range of decarbonization pathways that inform the overall applicability of lessons learned from the Pilot to the broader population in the state. Related but distinct metrics like percent of buildings, area, emissions, and average energy use intensity (EUI) provide information about the market share, decarbonization impacts, and scalability of a given typology. Understanding the rates of environmental justice or low-income households by building sector should inform the prioritization of specific typologies. Exploring the geographic distribution of buildings can ensure a prioritization of typologies that is more representative overall population of buildings.

Table 1. Overview of the value propositions, building characteristics, metrics and data sources used in this market characterization.

Value Propositions	Building Characteristic	Key Metrics	Key Data Sources
• High-impact scaling • Env. Justice • Applicability	• Primary Use • Size • Vintage / associated envelope considerations • HVAC System • DWH Type • Heating Fuel • DHW Fuel	• Buildings (%) • Sq. Footage (%) • Energy use (%) • Fossil energy use on-site (%) • EUI (kBTU/sq. ft.) • Emissions (% CO_2eq) • Geo. Dist. By Reg. Planning Agency • Env. Justice / Low-income status	• City and County Commercial Building Inventories (NREL/CoStar) • Comstock (NREL) • ResStock (NREL) • CBECS (US EIA) • MassGIS • Literature reviews (various)

To estimate the market share of different building typologies by count, square footage, energy use, and emissions we used a combination of public data sources that were supplemented by literature review. Using a combination of data sources was required because no single source had all the required fields or had adequate sample sizes of buildings to accurately estimate the market share of detailed typologies. These data sources and their uses in this analysis are summarized in Table 2.

Table 2. Overview of key data sources used for this market characterization.

Source	Description	Primary Use
Literature Review	Published market studies such at MA Decarbonization Roadmap Building Sector Report, Mass Save & DNV-GL C&I characterization, Carbon Free Boston Buildings Technical Report.	Guiding insights to prioritization considerations in existing building stock, key challenges with typologies, state goals and recommended pathways.
City and County Commercial Building Inventories	NREL county-level modeled estimates of commercial building population for 2018 based on CoStar Reality database.	Estimate total building population count and area by use type, vintage, and size class. Truing up totals from less-granular data sources.
ComStock	6,621 DoE building energy models representative of MA commercial buildings in 2018 for most-common use types.	Estimate frequency, energy use, emissions by use type, HVAC system, water/heating fuels, CEJST DAC designation, etc.
ResStock	11,690 DoE building energy models representative of MA residential buildings in 2018.	Estimate frequency, energy use, emissions by use type, HVAC system, water/heating fuels, low-income status, etc.
Commercial Building Energy Consumption Survey (CBECS)	EIA CBECS Survey Microdata for the 285 records in New England.	For building types not in ComStock, estimate frequency and energy by use type, HVAC system, and water/heating fuels.
Massachusetts Environmental Justice GIS System	Designated EJ Group Blocks based on the definitiion created in the Massachusetts Climate Bill in 2021	Used to establish the prioritization of certain building typologies in he Pilot program
Other	US Census Data, County Business Patterns, MA assessor data, MA GIS files etc..	Used if/as needed to validate results and add higher resolution to spatial analysis of patterns of building types across MA.

A review of recent literature, especially the *Massachusetts 2050 Decarbonization Roadmap Building Sector Report*[1], *MA C&I Market Characterization On-Site Assessments and Market Share and Sales*

[1] The Cadmus Group et al. 2020. Massachusetts 2050 Decarbonization Roadmap Building Sector Report. https://www.mass.gov/doc/buildings-sector-technical-report/download

Trends Study[2], and *Carbon Free Boston Buildings Technical Report*[3], was used to inform our approach to market characterization, typology development, and prioritization.

To estimate the total Massachusetts commercial building population square footage and count by use type, and vintage, we relied on City and County Commercial Building Inventories[4] developed by NREL and based on a detailed real estate database available from CoStar. Although this data source is modeled as opposed to actual tax parcel data, it was our most granular source of information about the state building stock with approximate 80,000 records at the county or township level. For this reason, this NREL/CoStar data source was also used to "true up" or re-weight the market share estimate based on other data sources with fewer records. Although, we recognized that it would be possible to get more accurate and geographically detailed building stock estimates from public tax parcel data, we determined that processing the data source was not practical given the timeline and scope of this market assessment.

For detailed analyses of the building stock including estimated frequency, energy use, EUI and emissions from buildings with combinations of use types, HVAC system, DHW types, fuel types, and Environmental Justice/Low-income designation, we relied primarily on NRELs ComStock[5] and ResStock[6] population of building energy models for Massachusetts. Thedata from ComStock and ResStock include thousands of detailed building energy model results for a sample of commercial and residential building typologies. The collection of models was designed to be representative of the building sector in 2018. ResStock includes models to represent the entire multifamily sector, but ComStock is missing some building types like public assembly, religious worship, and laboratories which represent a relatively small fraction of the population.

To characterize the building systems and energy use patterns in the use types missing from ComStock, we used CBECS data for the northeast region. Unlike Comstock and ResStock, the Commercial Buildings Energy Consumption Survey (CBECS)[7] is based on surveys of building occupants. Although the US EIA applies weights to records in the data to make the summary statistics based on the data more representative of the overall population of buildings, in some cases the underlying sample of surveys can be quite small, limiting our ability to characterize the building systems and fuels for some use types such as groceries. Another limitation of using CBECS is that unlike ComStock and ResStock, there are not data fields that allow us to designate buildings as either low-income or within EJ communities. So these types were excluded from those specific analyses.

MARKET CHARACTERIZATION

This section summarizes the results of analyzing the market share of commercial buildings with different characteristics. The results of these summaries inform the creation of the recommended typologies for inclusion in the Pilot.

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[2] DNV-GL. 2016. MA C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study. https://ma-eeac.org/wp-content/uploads/MA-CI-Market-Characterization-Study.pdf

[3] Arup Group Ltd. & Boston University. 2019. Carbon Free Boston Buildings Technical Report. https://www.boston.gov/sites/default/files/file/2020/08/CFB_Buildings_Technical_Report_061719_0.pdf

[4] City and County Commercial Building Inventories - Catalog (data.gov)

[5] OEDI: End-Use Load Profiles for the U.S. Building Stock (openei.org)

[6] OEDI: End-Use Load Profiles for the U.S. Building Stock (openei.org)

[7] Energy Information Administration (EIA)- Commercial Buildings Energy Consumption Survey (CBECS) Data

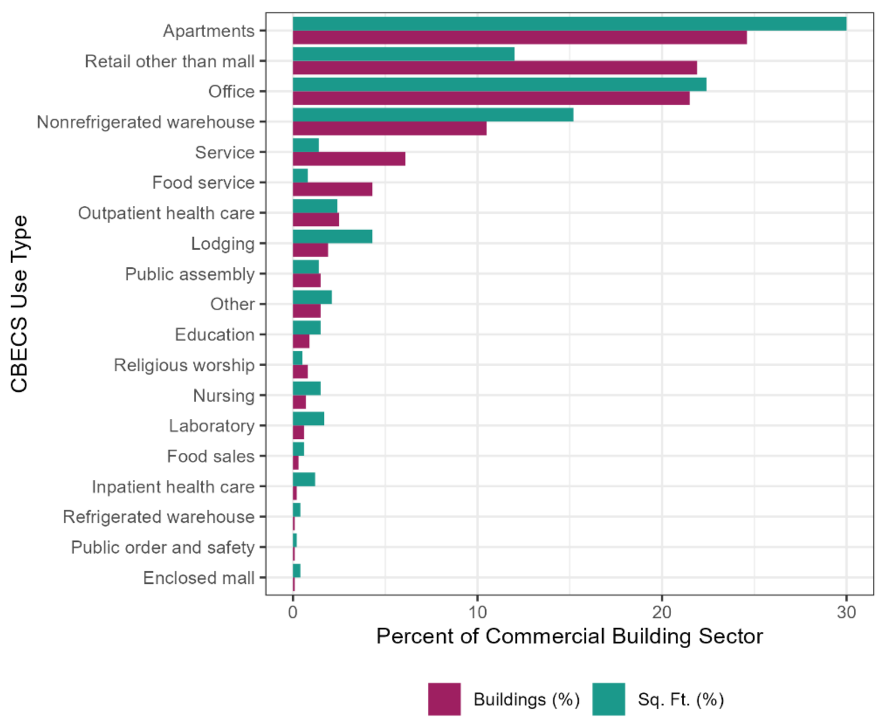
MARKET SHARE BY BUILDING USE TYPE

This section outlines the process by which we aggregated the preliminary CBECS-based building use type categories to create the final categories used for the detailed analysis in sections that follow. It also compares the market share of the aggregated use types on the basis of building counts, total area, energy use, and emissions.

Preliminary Use Types

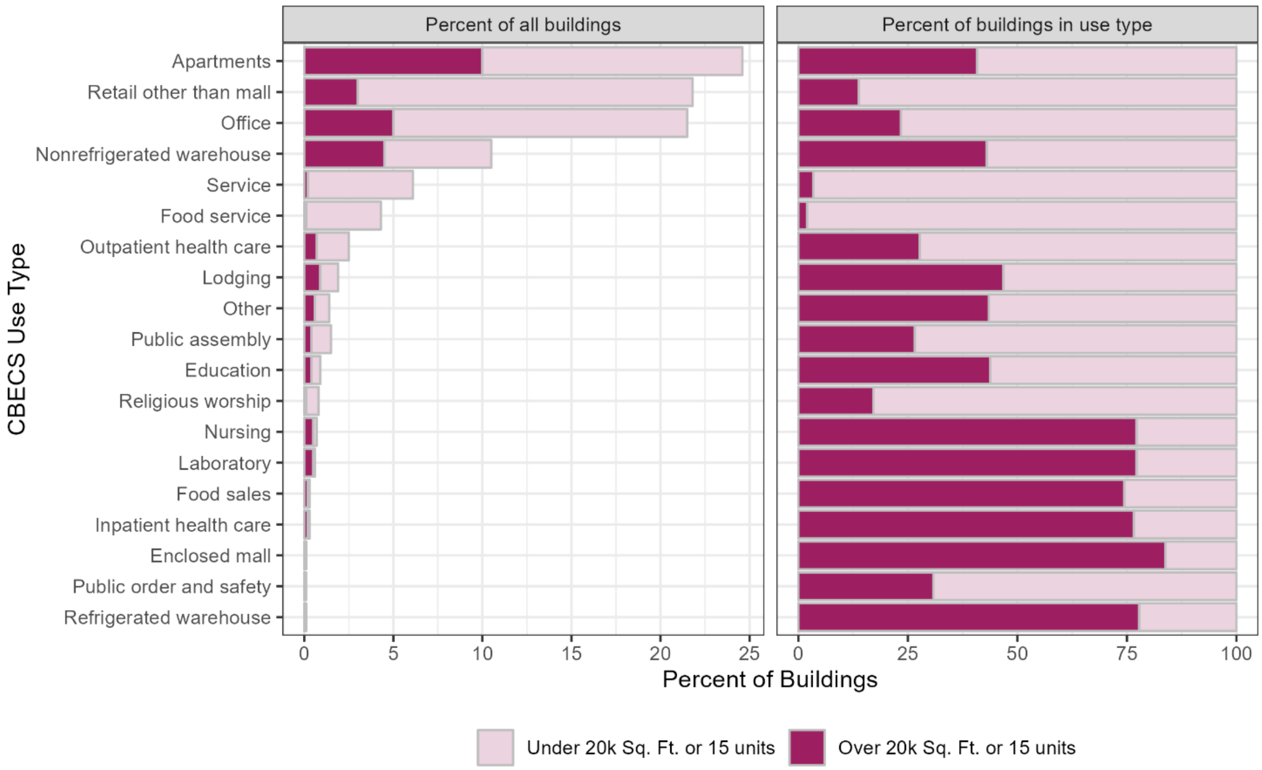
As a starting point, the NREL/CoStar data was used to explore how the population of commercial building types within Massachusetts is distributed among the standard detailed building use types used in CBECS. Figure 2 shows the breakdown of these building use types by total area and number of buildings. The starting population includes all commercial and multifamily buildings regardless of size and only excludes industrial buildings. This sample includes approximately 76,000 buildings and 2 million square feet. Based on both metrics, Apartments, Retail, Office and Service, Food Service make up the most prevalent use types.

Figure 2. Estimated percentages of all commercial and multifamily buildings in MA by CBECS use type categories.



In alignment with Boston's Building Emissions Reduction and Disclosure Ordinance BERDO, the Pilot has set working criteria for minimum size thresholds for participation: >20k sq. ft. for commercial buildings and >14 units for multifamily apartments. After this threshold is applied, we see that some use types that are skewed toward smaller buildings, like service, food service, small retail, and religious worship make up much less of the market share (Figure 3). The analysis of commercial buildings that follows in this report only includes buildings that meet the minimum size thresholds.

Figure 3. Percent of all commercial buildings in MA above and below minimum size thresholds by use type (left) and percent of commercial buildings within each CBECS use types falling above and below size thresholds (right).



Aggregated Use Types

To simplify the comparison of building characteristics between typologies, e.g. HVAC systems, energy use, heating fuels, etc, we combine some of the CBECS typologies as follows:

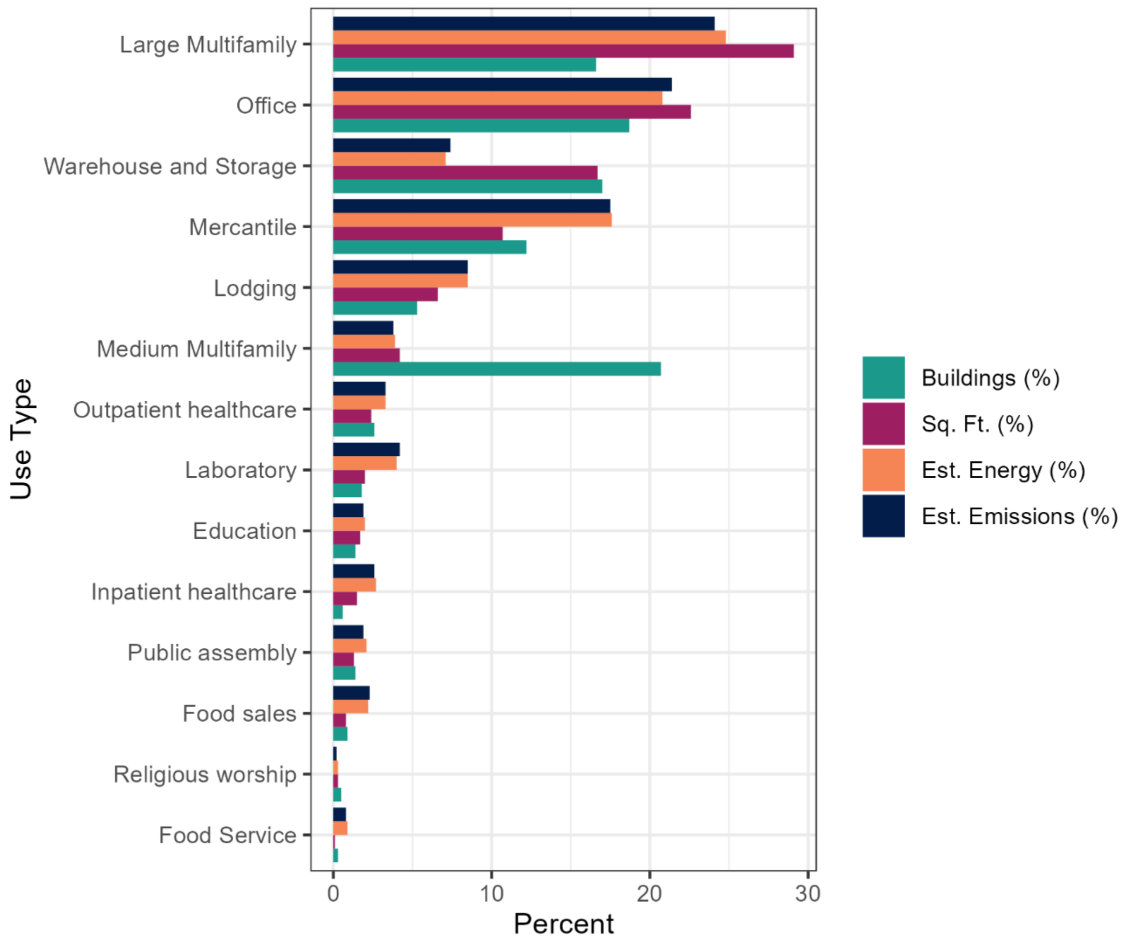
- **Medium Multifamily**: apartments, dormitories, and nursing facilities with 15-49 units.
- **Large Multifamily**: apartments, dormitories, and nursing facilities with 50+ units.
- **Mercantile**: all retail including malls, stand-alone, and service businesses.
- **Warehouse and storage:** all warehouse and storage including both refrigerated and unrefrigerated.

The "Other" category was dropped from the subsequent analysis since buildings in that heterogeneous category are not easily categorized or prioritized for decarbonation. Figure 4 compares the market share of the aggregated building use types by building count, total area, total energy, and total annual emissions (CO_2eq).[8] In most cases the use types compare similarly across the four metrics of market

[8] Emissions were estimated by applying calculating mean emissions intensity by use type and scaling based on ComStock, ResStock and CBECS and scaling by total building area for the use type based on the NREL/CoStar data.

share. The main exception being that medium multifamily buildings comprise a significant market share based on building count but a smaller share by other metrics. This is likely because, unlike the other use types that exclude buildings under 20k sq. ft., multifamily is screened by number of units and includes more small buildings below the 20k sq. ft. threshold. By other metrics, large multifamily, office, warehouse and storage, mercantile, and lodging represent the majority of the market share.

Figure 4. Market share of aggregated building use types by buildings, total area, total energy use, and total emissions.



The market share percentages for each use type along with estimated building count and mean energy use intensity (EUI) are shown in Table 3. Food service, food sales and laboratories have the highest EUI values but relatively small market shares by other metrics.

Emissions factors for different fuels were taken from the Boston Building Emissions Performance Standard (2021) and EPA's eGRID Database (2023). Total energy by use type was estimated similarly: calculating mean EUI by use type and scaling by total area for same use type in NREL/CoStar data.

Table 3. Summary statistics on primary use typologies characterized in this study.

Study Use Cat.	Buildings	Est. EUI (kBTU/ft^2)	Buildings (%)	Area (%)	Energy (%)	Emissions (%)
Medium Multifamily	4,236	57.8	20.7	4.2	3.9	3.8
Large Multifamily	3,392	53.1	16.6	29.1	24.8	24.1
Office	3,829	57.1	18.7	22.6	20.8	21.4
Warehouse and Storage	3,490	26.5	17	16.7	7.1	7.4
Mercantile	2,510	102	12.2	10.7	17.6	17.5
Lodging	1,091	79.4	5.3	6.6	8.5	8.5
Outpatient healthcare	525	84.2	2.6	2.4	3.3	3.3
Laboratory	358	125.5	1.8	2	4	4.2
Public assembly	297	99.6	1.4	1.3	2.1	1.9
Education	287	73.3	1.4	1.7	2	1.9
Food sales	183	182.9	0.9	0.8	2.2	2.3
Inpatient healthcare	128	114.3	0.6	1.5	2.7	2.6
Religious worship	103	49.2	0.5	0.3	0.3	0.2
Food Service	64	409.6	0.3	0.1	0.9	0.8

BUILDING SIZE AND VINTAGE

Building size and vintage are two main characteristics that can provide additional context within a specific building use type. Size is used to establish general building categories and assess correlations with other factors like HVAC complexity. Vintages are used to help prioritize buildings within a given type and help ascertain the potential for load reduction strategies involving envelope upgrades.

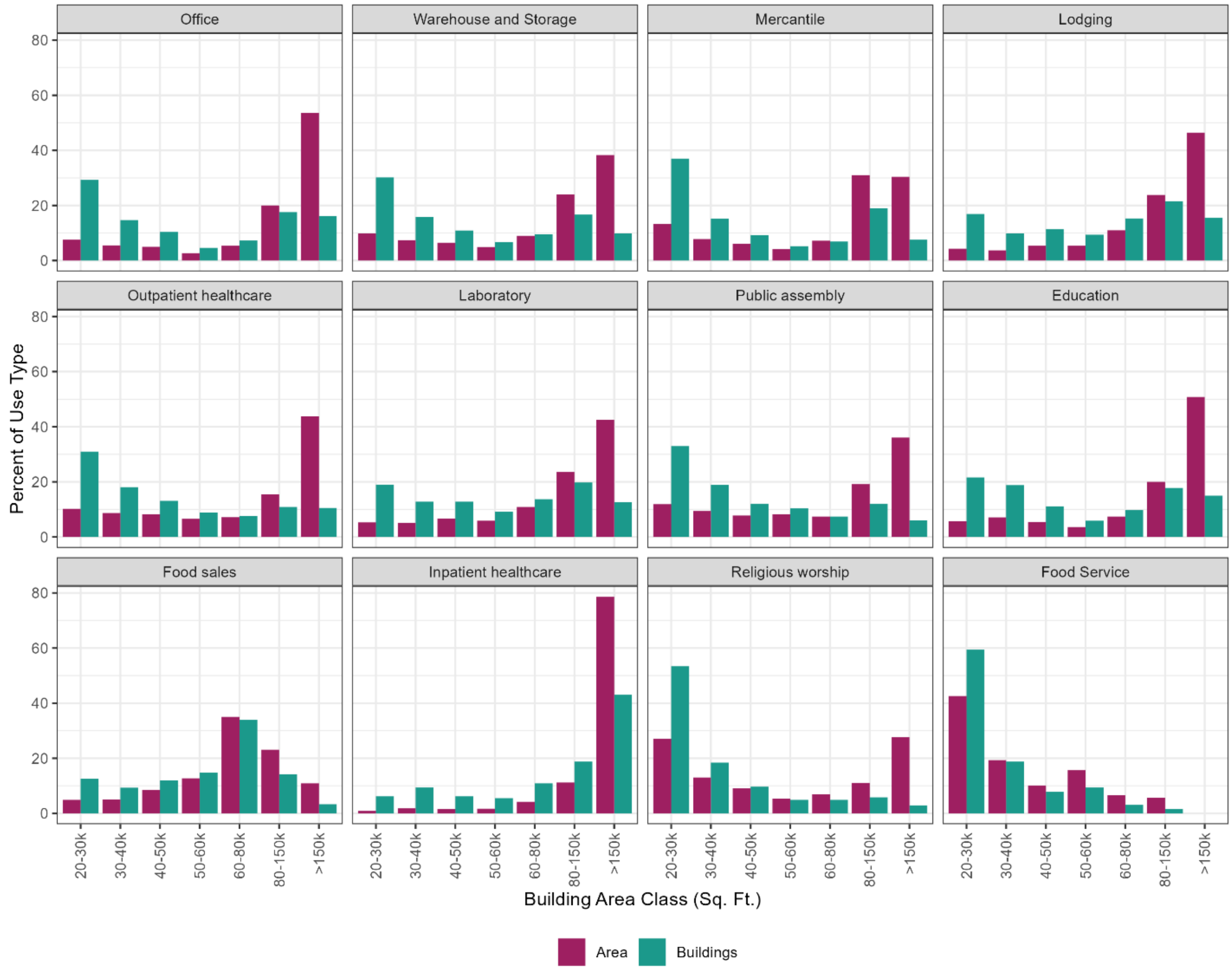
Size

Building typologies have been binned in square footage categories to assess size-related considerations such as the impact of applying the proposed 20,000ft^2 and 15-unit thresholds aligned with the building benchmarking requirements used by Boston's Building Emissions Reduction and Disclosure Ordinance (BERDO). The city of Cambridge is also closely aligned with these thresholds within their Building Energy Use Disclosure Ordinance (BUEDO). Other relevant decarbonization factors related to building size include the sophistication of building operations, capital planning considerations, as well as potential correlations such as HVAC complexity, energy use intensity, and environmental justice considerations. Although each of these elements were not explicitly characterized in this study, an understanding of prevalent size distributions within each typology was developed, allowing for a targeted approach for prioritizing buildings by size.

For many of the building typologies, medium buildings were defined as falling within 20,000 ft^2 to 50,000 ft^2 or 15 to 50 units for multifamily buildings. Large buildings exceed these thresholds.

Figure 5 provides a detailed size distribution by building type. Some distributions including office, warehouse and storage, and mercantile have a higher frequency of both smaller and large buildings but relatively fewer "mid-size" structures. For both of these types, more than half of the area falls within the largest buildings. Some building types show a spike in frequency within typical sizes: many food sales buildings fall within the mid-size ranges, in-patient healthcare and lodging are predominately large, and food service skews toward smaller buildings.

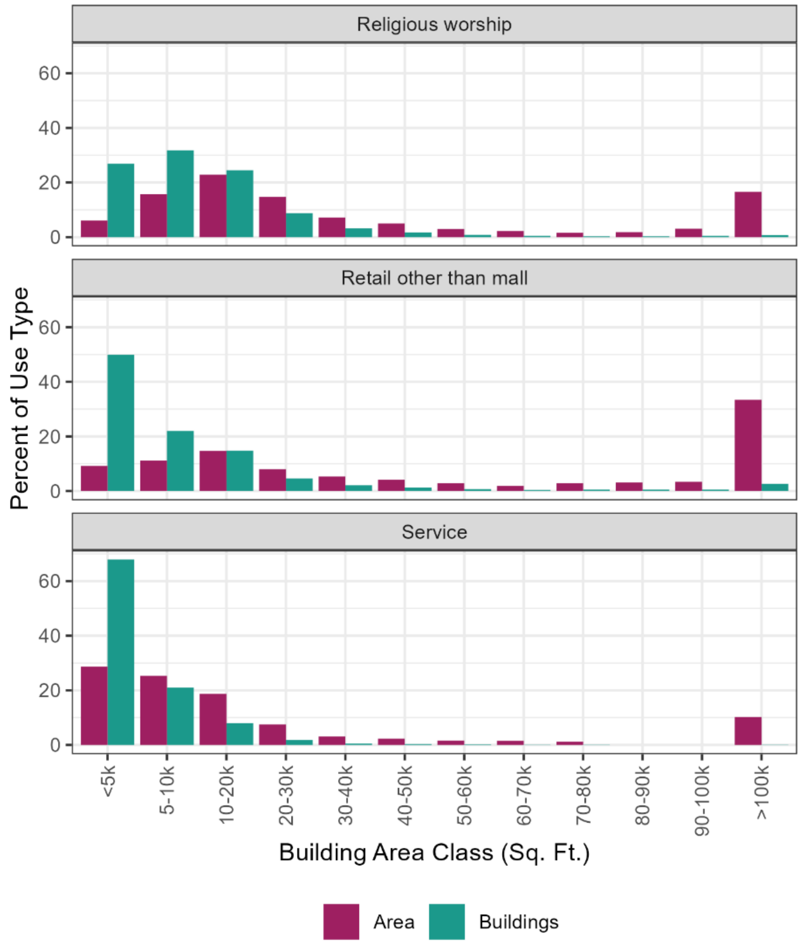
Figure 5. Size distribution of commercial buildings over 20,000 square feet.



One area for consideration within this study is the threshold in which to pursue multifamily building typologies. While multifamily buildings are the most common building type and show the most promise for emissions reductions though electrification, they are also the most studied and supported based on existing research and programs. As a potential cutoff, we may only investigate larger, i.e. greater than 50 unit buildings, which could see the most benefit from the Pilot as they are likely more complex and challenging to retrofit. About 55% of multifamily buildings within the commonwealth are over 50 units representing the largest emissions category of the building pool analyzed.

Service businesses, small retail, and religious worship buildings are likely most impacted by the minimum size criteria. While a substantial number of buildings remain that are larger than 20,000ft^2 most of these buildings are smaller than that threshold: >80% of religious worship, 85% of small retail other than mall, and >95% of service buildings. Figure 6 shows the breakdown the size distribution of these building types. The decarbonization pathway of these small sized building types may be similar to that of residential homes. However, current outreach and training mechanisms may not target these owners or contractors to seek electrification or specific load reduction strategies. Future considerations could be made to target small commercial decarbonization sectors.

Figure 6. Size distribution of all smaller use types without applying a minimum size threshold.



Vintage

Three vintage categories were compared to provide a proxy for building envelope and non-retrofit system performance. These vintage categories were designed to align with historical trends in construction practices and evolving energy code requirements. These categories are based on well documented approaches developed by NREL and the U.S. Department of Energy[9] to assess and benchmark historical commercial building energy consumption trends.

Pre 1980: These buildings had no energy code in place at the time of construction, thus limiting envelope insulation. There is a high potential for load reductions through weatherization measures and window retrofits.

1980-2004: Limited energy considerations were made at the time of construction resulting in marginal efficiency gains and some envelope insulation. There is a high potential for load reductions through weatherization measures and window retrofits.

[9] U.S. Department of Energy, Commercial Reference Building Models of the National Building Stock. https://doi.org/10.2172/1009264

2004+: These buildings were built to a substantial energy code driving performance for building insulation and systems. Projects from these vintages are less likely to see significant cost-effective benefits from insulation upgrades.

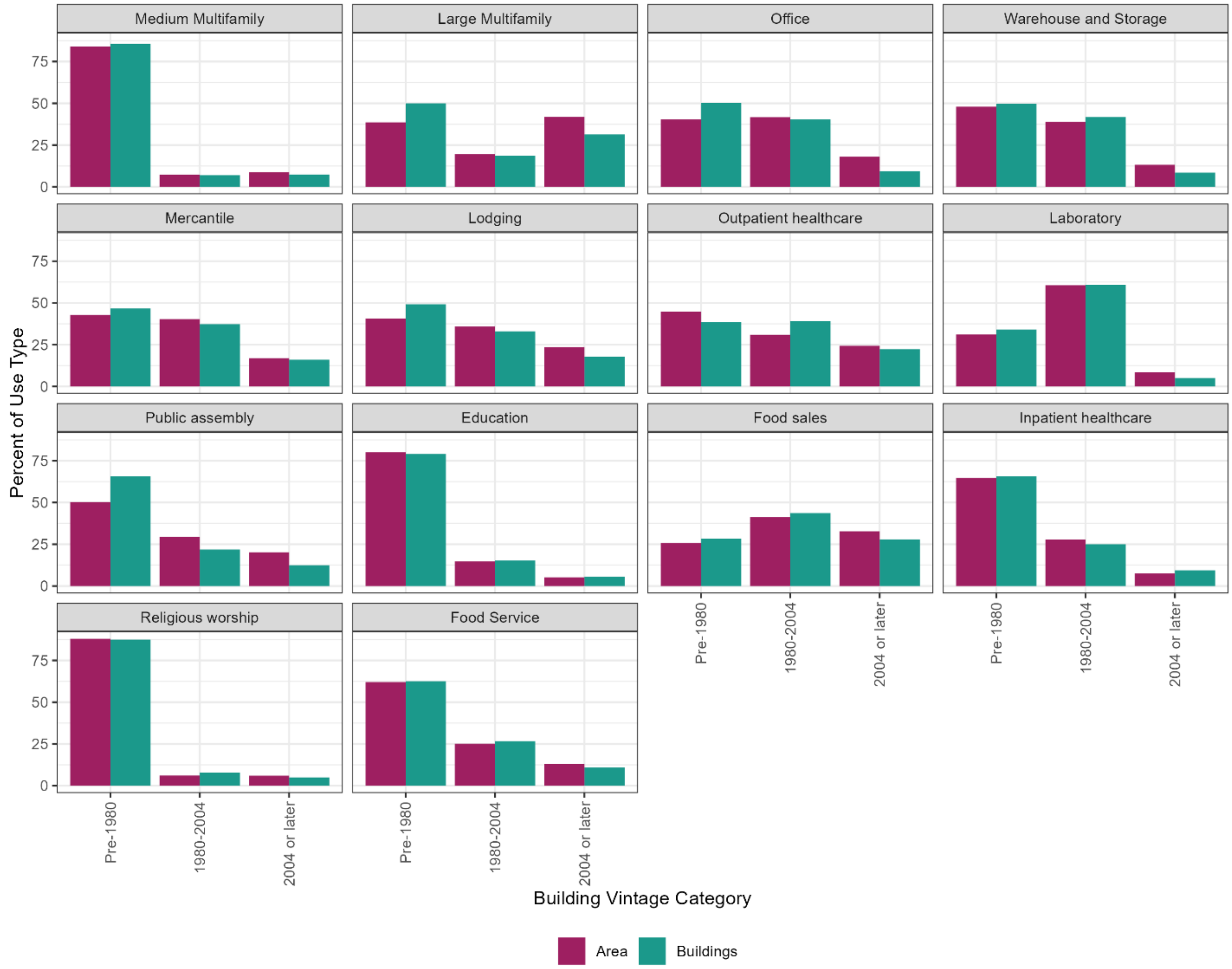
Most buildings in the Commonwealth studied pre-date 1980 and are considered to have low envelope performance. As buildings have general become larger in size over time, post-1980 and later construction represents the largest area percentage.

Table 4. Vintage breakdown of total population of commercial buildings by count and area.

Vintage	Buildings (%)	Area (%)
Pre-1980	57.1	44.4
1980-2004	28.8	31.9
2004 or later	14.1	23.7

Figure 7 provides a breakdown of vintage by building count and total area use for each of the main building typologies studied. Several building types skew towards older vintages such as medium multifamily, education, inpatient healthcare, and religious worship. The brick and stone construction methods prevalent with these larger buildings can pose additional challenges to increasing overall insultation as part of a holistic decarbonization strategy. Other building types are more evenly distributed and likely vary more in their construction methods with wood and metal framing providing more opportunities for envelope retrofits depending on vintage.

Figure 7. Vintage breakdown on the basis of building count and total area by use type.



ENVIRONMENTAL JUSTICE AND INCOME

To explore broad patterns in the Environmental Justice designation and low-income status among buildings with different characteristics, we used indicators included in the ComStock and ResStock data. ComStock indicates whether a modeled building falls within a census tract designated as disadvantaged based on the US Council on Environment Quality Justice40 definition.[10] This definition is similar to that used by the MA EEA to designate Environmental Justice (EJ) populations.[11] This EJ indicator was used to assess whether some commercial building types are more represented in disadvantaged census tracts. As illustrated the map of Boston in Figure 8, many census tracts designated as disadvantaged by the Justice40 definition (left) overlap with areas designated as EJ populations by MA EEA (right).

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[10] Methodology & data - Climate & Economic Justice Screening Tool (geoplatform.gov)

[11] MassGIS Data: 2020 Environmental Justice Populations | Mass.gov

Figure 8. Environmental Justice Mapping Comparison for the Greater Boston Metro Area.

Climate and Economic Justice Screening Tool | **EEA Massachusetts Environmental Justice Populations**

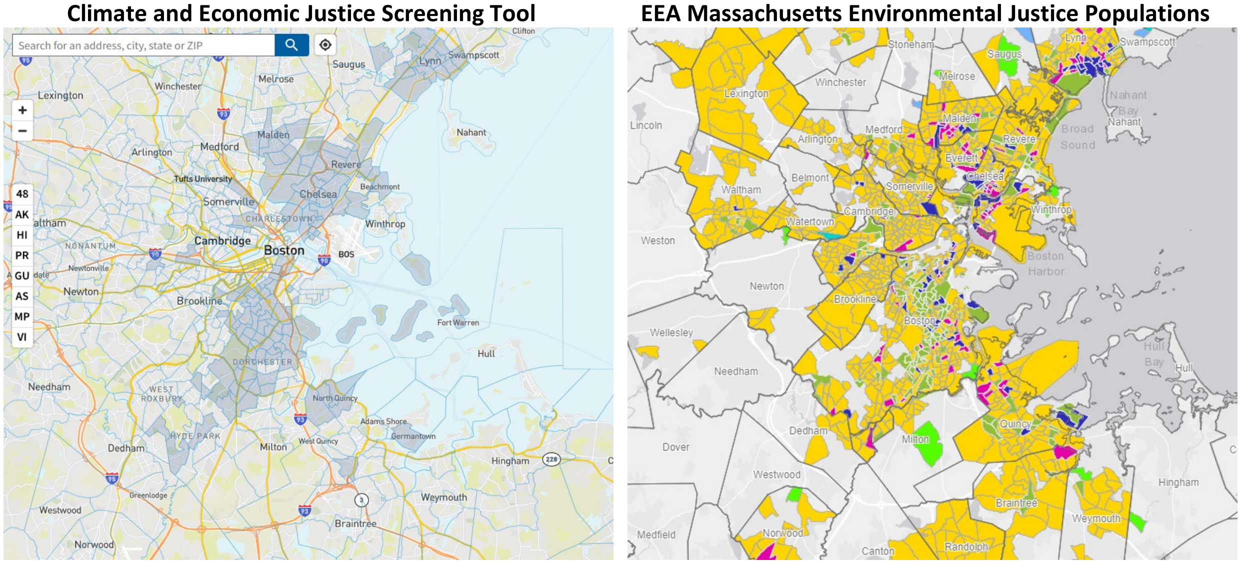

Image credit: https://screeningtool.geoplatform.gov/en

Image credit: https://mass-eoeea.maps.arcgis.com/apps/

As for income, the ResStock data indicates the income of multifamily building as a ratio of the federal poverty level (FPL). Income is the metric used in common in disadvantaged community definitions and a key requirement for many government and utility programs serving vulnerable populations. Multifamily buildings in ResStock with an income level of 200% of the FPL or less were designated as low income for this analysis. Note that this income threshold, which represents approximately 40% of estimated state median income (SMI) in 2023, is more stringent than the 60% SMI threshold for MassSave Income Eligible Programs. [12] Therefore, this analysis targets a subset of lower income multifamily households which would also qualify for MassSave programs.[13]

We conducted a combined analysis of the ResStock and ComStock data. Therefore, characteristics like use type were compared using a single indicator, which designated a given building model as representing being either low-income multifamily building or a commercial building within an EJ census tract. The use types available only in the CBECS data (religious worship, public assembly, laboratory, and food sales) were excluded from this analysis due to a lack of relevant indicators. It is important to note that some building types in ComStock, like in-patient health care (N=15), food service (N=58), and lodging (N-81), have a smaller sample sizes of models, limiting our ability to draw conclusions about the distribution of the use types between EJ and Non-EJ tracts within Massachusetts, i.e. differences may be due to some random variation in how the NREL building models were distributed across the state.

Table 5 compares the mean EUI between buildings designated is EJ/Low-income and shows the market share of the buildings by this indicator. Overall, the mean EUI is similar between EJ/Low-income and Non-EJ/Not Low-income tracts and the market share breakdown is also comparable across metrics, i.e. approximately 34% of the building sector is EJ/Low-income designated.

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[12] See this table for comparison of income thresholds based on FPL percentage versus 60% of state median income for households if different sizes in 2023: https://www.mass.gov/doc/fy-2023-liheap-income-eligibility-and-benefit-level-chart-december-5-2022/download

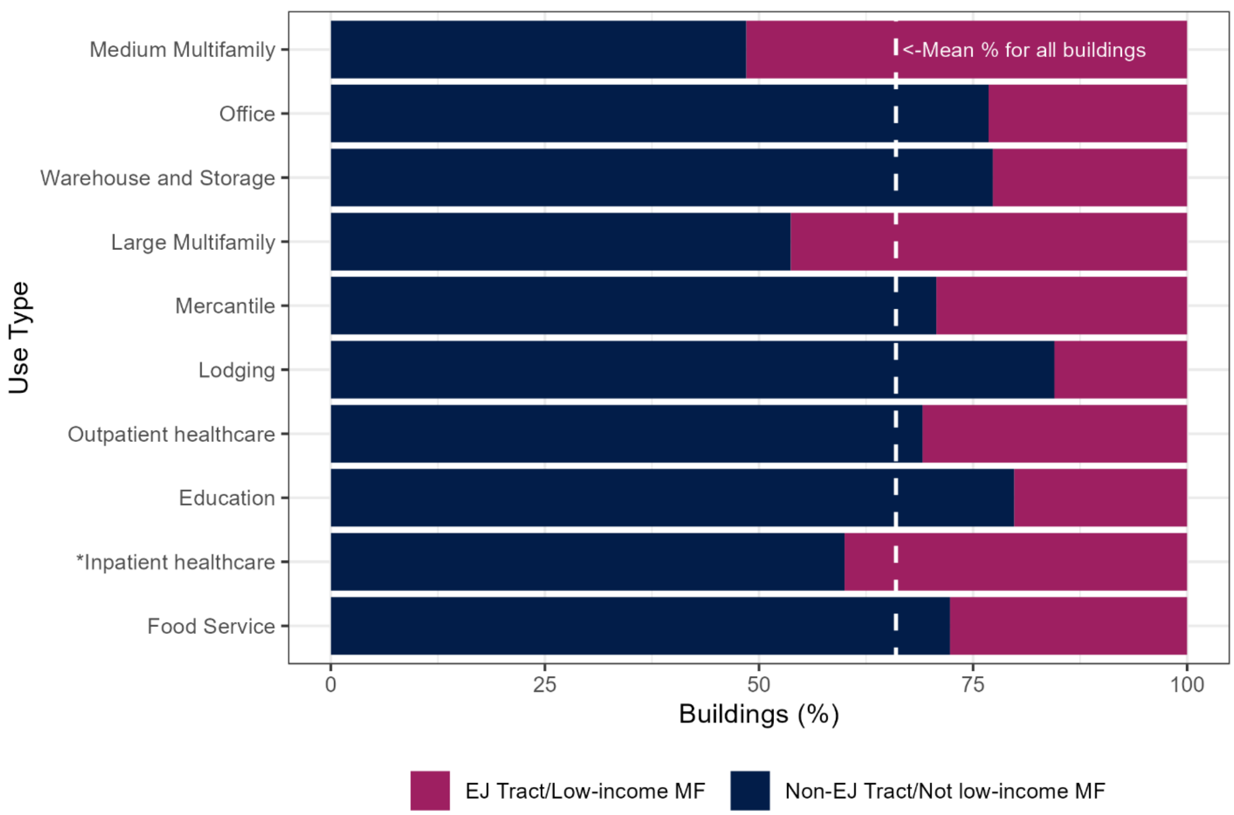
[13] See this table for MassSave 2023 program low income thresholds based on 60% of SMI: https://www.masssave.com/en/residential/programs-and-services/income-based-offers/income-eligible-programs

Table 5. Comparion of EUI and market share of building sector by EJ/Low-income designation.

EJ Tract / Low-income Multifamily	Total EUI (kBTU/ft2)	Buildings (%)	Sq. Ft. (%)	Total Energy (%)	Fossil Energy (%)
Non-EJ Tract/Not low-income MF	60	66.3	67.3	64.6	64.7
EJ Tract/Low-income MF	65	33.7	32.7	35.4	35.3

An important question for prioritizing building typologies is whether key characteristics like use type and vintage are more likely to be associated with EJ/Low-income buildings. Figure 9 shows the percent of buildings of each use type available in the ComStock and ResStock data that are designated as EJ or low-income. We see that the percentages for most use types are near the mean for all buildings (66% Non-EJ/Not Low-income as show in vertical dashed line). The notable exceptions are the multifamily building types. Approximately 50% of both large and medium multifamily buildings in the sample fall at or below 200% FPL.

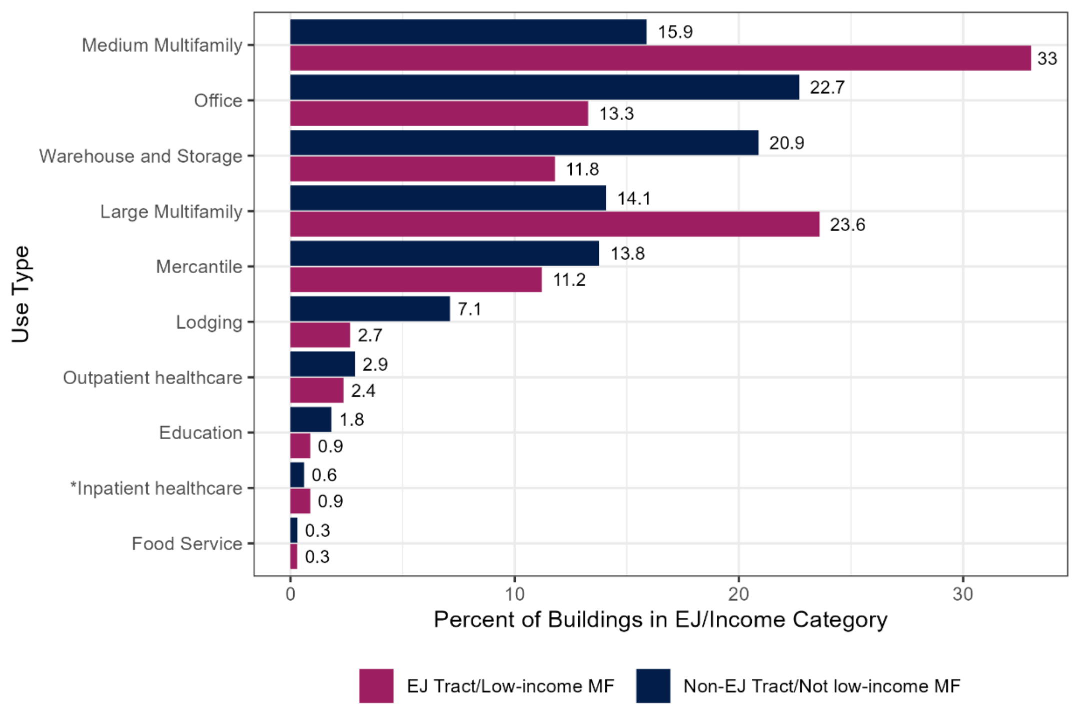
Figure 9. Percentage of bulidings within use types desigated as EJ or low-income mulitfamily.



**Interpret with caution due to small sample size (N=15)*

Although some use types like multifamily buildings are more likely to be designated as low-income, it is useful to note that other common building types make up a significant percentage of the overall population of EJ/Low-income buildings simply by virtue of being the most prevalent. As shown in Figure 10, office (22.7%), warehouse and storage (22.9%), and mercantile (13.8%) collectively make up more than half of these EJ/Low-income buildings in the sample even through within each use type the fraction of EJ-designated buildings is between 20-25%. In addition, by comparing the percentages of use type in the pool of EJ/Low-income vs Non-EJ/Not Low-income buildings, we can compare the use type's relative importance within the EJ/Income groups. For example, Medium Multifamily buildings are twice as prevalent in the EJ/Low-income pool of buildings compared to the Non-EJ/Not Low-income pool of buildings (33 vs 15.9%), while lodging is half as prevalent (2.7 vs 7.1%).

Figure 10. Building use type percentages of all EJ/Low-income multifamily vs all Non-EJ/Not Low-income multifamily buildings.



Interpret with caution due to small sample size (N=15)

An exploratory analysis of how other characteristics differentiate building typologies by EJ or income status did not reveal any significant patterns. For example, for the sample of building models, the distribution of building age and size was similar regardless of EJ or income status.

In conclusion, the purpose of this analysis was to identify any strong signals that would indicate typologies, i.e. use types, HVAC system, vintages, and sizes, that are much more prevalent in EJ communities. The only significant finding was that, not surprisingly, multifamily buildings should be prioritized on the basis of EJ considerations.[14] To some extent, the absence of more observed correlations between building attributes and EJ indicators, is due to the limitations of the data used for

[14] Based on 2020 census microdata, the average household income for households in multifamily buildings is 58% of that for households in single-family home.

this analysis. With a more granular spatial analysis of detailed building typologies more patterns would likely emerge.

It is important to note that environmental justice designation is an important, complex, multifaceted topic which is also subjective, evolving with multiple state and national definitions. Full consideration of environmental justice implications for prioritizing buildings for this Pilot requires careful attention to those neighborhood, building, and occupant characteristics that both describe vulnerable populations and have important implications for building decarbonization. These include, but are not limited to income, historical redlining, race/ethnicity, pollution burdens, and ownership. In addition, identifying vulnerable populations and the building typologies that provide important services to those communities should be informed by local knowledge and experience within these communities. For this Pilot, we recommend that the EJ metrics used to prioritize typologies for participation be honed through additional discussions with the project team and relevant stakeholders. In turn, the identified EJ priorities should be used primarily in the recruitment screening process rather than preliminary typology development.

HVAC AND HOT WATER SYSTEMS

HVAC and domestic hot water (DHW) systems are the two largest end uses of on-site fossil fuel in commercial buildings. Commercial kitchens and process loads also play a significant role but were not included within this market summary analysis as they are typically limited to specific building types. Based on CBECS, space heating accounts for 75% of direct fossil fuel use in large commercial buildings in New England, while DHW systems account for another 14%. The goal for this section of the market summary is to investigate the types of systems used across the building typologies outlining their commonalities, prevalence, and intensity of fuel use.

HVAC Systems

HVAC types are categorized into five main groups based on ComStock and ResStock groupings. These differentiate between central residential style, zone-by-zone, multizone CAV/VAV Small packaged unit, and other. These groups provide a simplified approach to investigating a multitude of HVAC systems at a high level. HVAC system electrification has the largest potential for emissions savings across most commercial building typologies. However, these systems vary significantly and depending on distribution, controls, and heating sources may require nuanced solutions. Additional investigation into detailed HVAC types and comparisons between complex and simple systems is also provided.

Small Packaged Unit: These are factory-built units that typically contain a fan, gas heating coil, direct expansion cooling, and an outdoor air intake. Often, they are roof mounted and have less than a 10-ton capacity. Multiple units may serve a single building.

Residential style central systems: These are ducted systems that have a central furnace or air handler which provides heating and a split style cooling system. The unit is inside, and condenser system is outside. These are most recognizable from single family homes, but multiple systems can be used to heat or cool large residential or commercial building.

Zone-by-Zone: These are small individual pieces of equipment to heat and cool each zone within a building. They include through-the-wall packaged terminal air conditioners (PTACs), fan coil units, and zone-level water-to-air heat pumps. This category also includes boiler and baseboard systems which provide heating and may be supplemented with window AC units for cooling. Depending on building type, ventilation air is conditioned and supplied to the zone by a separate system, or not provided at all.

Multizone CAV/VAV Systems: These are forced air systems that simultaneously serve multiple thermal zones in the building, each of which has different heating and cooling needs using either constant volume or variable air volumes (VAV). Typically, these systems include large pieces of rooftop equipment or are a custom engineered system designed specifically for a building. Larger systems likely contain separate heating and cooling equipment like boiler based hot water coils and chillers for cooling.

Other: This small category contains HVAC systems not included within the above categories. It may contain systems like infrared heaters or destratification fans.

Table 6 provides a breakdown of energy usage and prevalence by HVAC grouping. The most diverse system type, zone-by-zone, also serves the largest share of buildings and square footage. Small packaged units are next followed by residential style central systems. While multizone CAV/VAV has a smaller share of buildings served, the ratio of square footage is relatively higher indicating these are more prevalent in larger buildings.

Table 6. Breakdown of HVAC groups by prevalence and energy characterisitics. Note that energy and emission values represent total building energy use including non-heating end-uses.

HVAC Type	EUI ($kBTU/ft^2$)	Buildings (%)	Sq. Ft. (%)	Total Energy (%)	Fossil Energy (%)	Emissions (%)
Zone-by-Zone	65	35	37.4	37.1	39.5	36.7
Small Packaged Unit	66	33.3	28.8	29	23.5	29.7
Residential Style Central Systems	52	23.3	19.4	15.4	19.3	15.3
Multizone CAV/VAV	85	8.2	14.2	18.4	17.6	18.2
Other HVAC	30	0.1	0.2	0.1	0	0.1

Figure 11 provides a summary of HVAC groups by building typology compared by prevalence. Typical HVAC groups are more frequent for certain typologies. The high prevalence of multifamily buildings using zone-by-zone system makes this system type the most common across buildings studied. Zone-by-zone is also dominant in lodging typologies and used by offices, warehouse, and laboratories to a lesser degree. Zone-by-zone is a diverse HVAC category with some systems like PTAC units proving a simple replacement opportunity for decarbonization while others like boiler-radiator systems will require a diverse range of solutions.

If only commercial non-multifamily buildings were considered, then small packaged units would be the most frequent HVAC group used across most of the prevalent building types. Packaged systems can be straightforward on a technical level to decarbonize through the utilization of heat pump RTUs. This solution is not without challenges due to costs, market availability, and operating limitations.

Residential style central systems are used to serve smaller commercial buildings with few thermal zones and are common in some large buildings like multifamily developments as a unit-based solution. Residential HVAC decarbonization is evolving yet optimized solutions are starting to emerge.

Multizone CAV/VAV typically occur in larger and more complex buildings so the typologies with a higher frequency to those characteristics like offices, inpatient healthcare, and education contain some of the highest proportions. These systems are inherently complex usually having separate heating and cooling components that are custom engineered for a particular application.

Figure 11. HVAC group frequency by use type

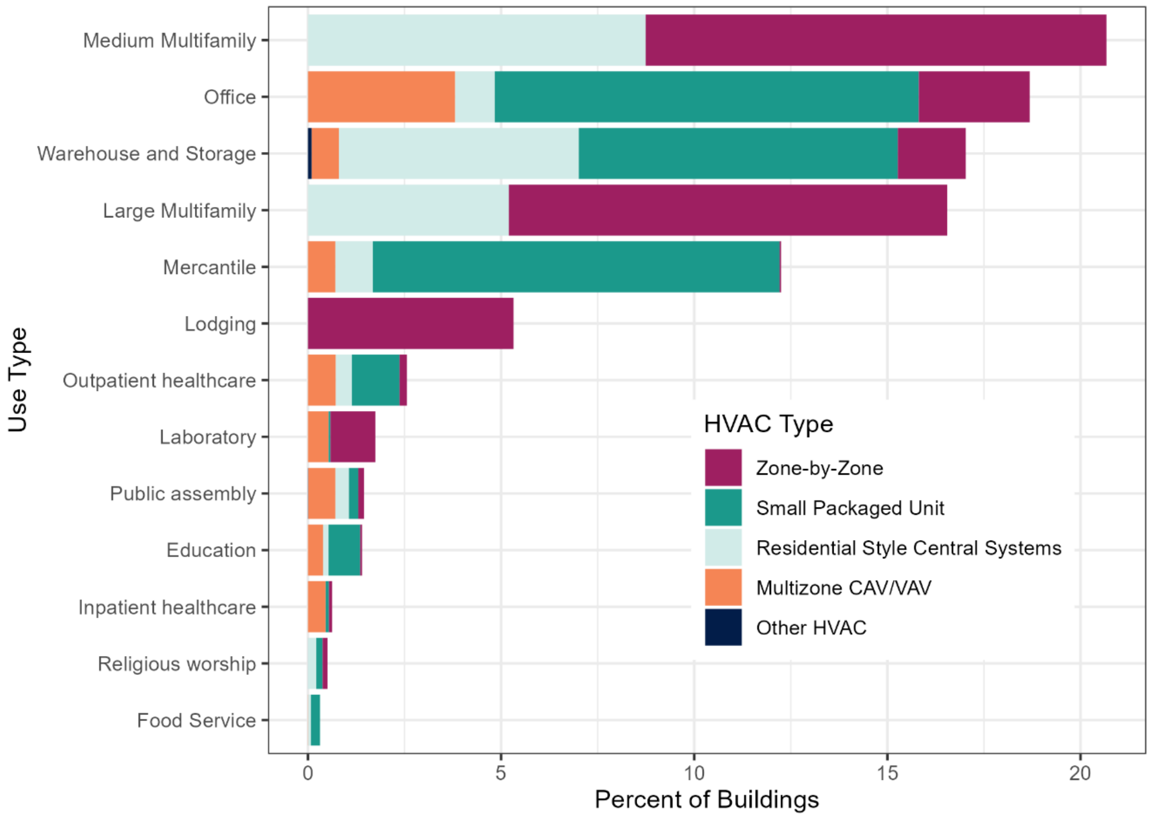


Figure 12 provides a slightly different way to visualize HVAC groups providing overall proportions by building typology. This gives greater resolution for the less common building types studied, like food service.

Figure 12. Proportion of HVAC groups by building type

While these HVAC groupings are helpful to understand the most common types of HVAC systems installed in each building type, we also want to understand if these HVAC systems will be simple or complex to decarbonize.

For this study we define **complex HVAC systems** as those which rely heavily on hydronic heating systems for things like radiators and VAV reheat. Removing combustion from these hydronic systems would be considered a complex undertaking in comparison to other HVAC systems. We also include water source heat pumps WSHPs which are connected to a boiler and DOAS systems. Other similar systems which could already have partially electrified heating sources like VRF technology, are also considered complex but would not be prioritized for decarbonization assessments.

Simple HVAC systems, on the other hand, can be more easily decarbonized with heat pump replacements through readily available and well utilized technologies. These include furnace-based solutions, electric radiators, and packaged gas fired or electric resistance rooftop equipment.

Figure 13 shows the prevalence of the detailed building system types and is color coded to indicate either the complex or simplified HVAC category. About 20 percent of buildings are considered to have complex HVAC systems.

Figure 13. Percentage of detailed building types and designation between simple and complex.

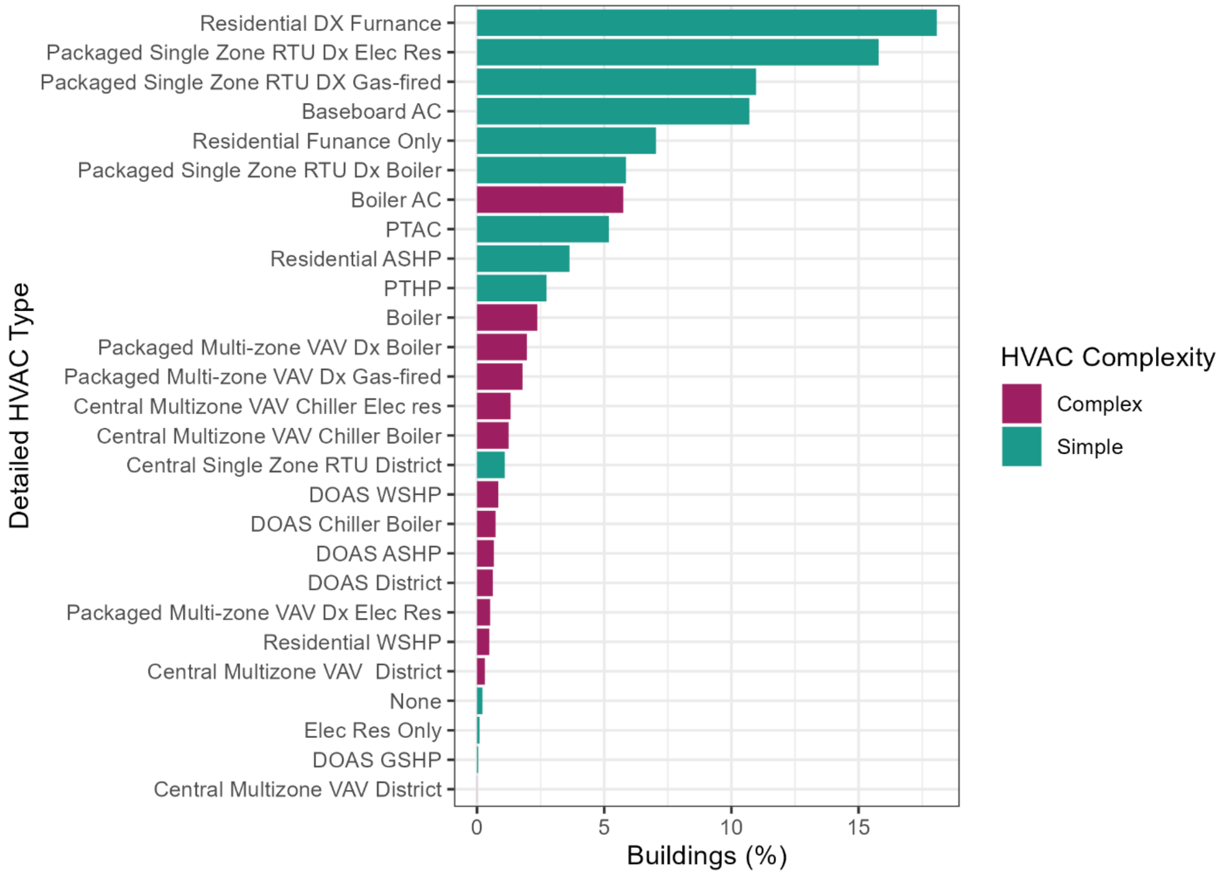
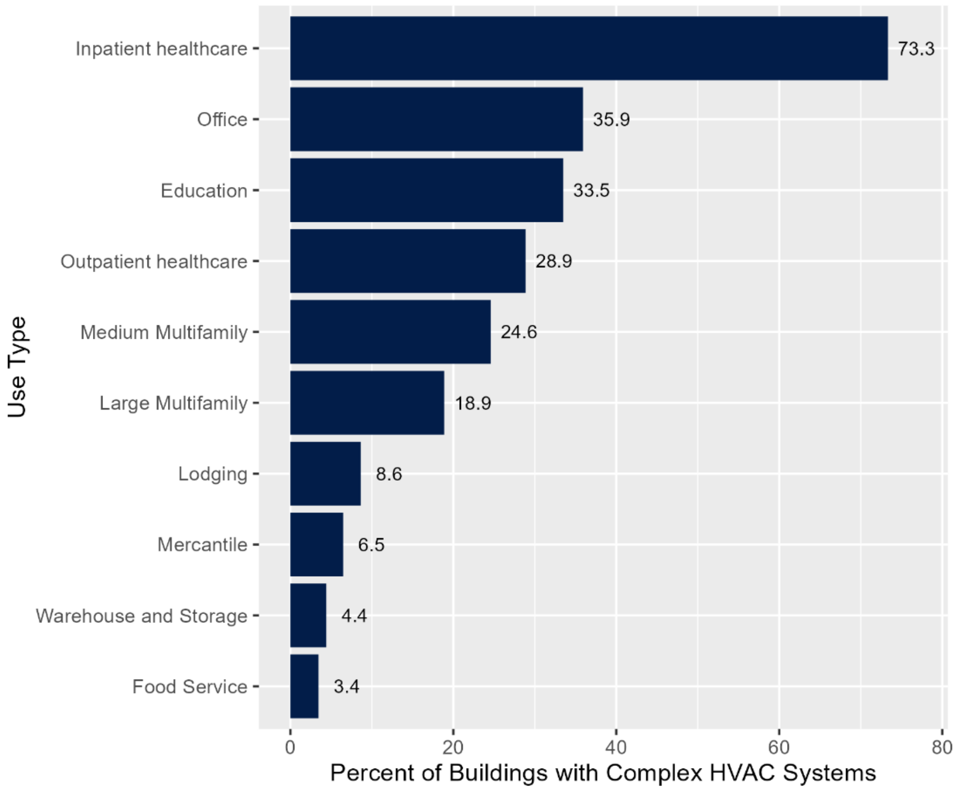


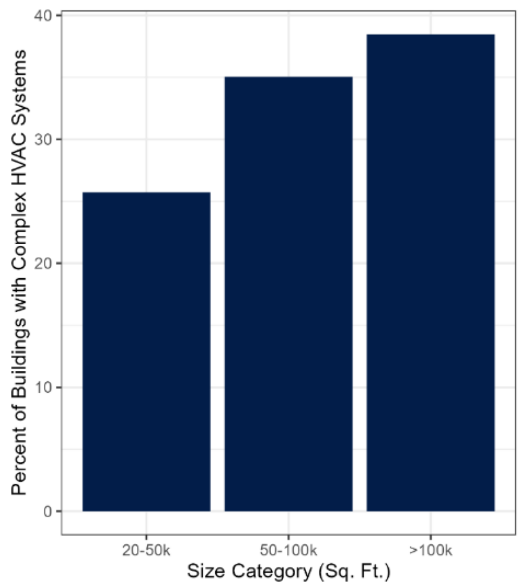
Figure 14 compares that percent of buildings in each use typology that have complex HVAC systems. Inpatient healthcare, offices, and education lead in this category. Note that data available for Laboratories, public assembly, and religious worship was not included in this specific assessment due to limited resolution within the data sets.

Figure 14. Overall percentage of buildings with complex HVAC systems.



In general, larger buildings have more instances with complex HVAC systems than smaller buildings. This is illustrated in Figure 15 which shows that larger offices tend to have more complex HVAC systems. According to a DNV Mass Save C&I characterization, buildings over 50,000ft[2] tend to have an energy management system or EMS aligning with complex HVAC systems.

Figure 15. Percent of office buildings with complex HVAC systems by size category.



Heating fuels

Reducing or eliminating on-site heating fuel usage is a key component of decarbonization. The amount of both fossil fuel and electric heating usage provides an indication of where and by what magnitude buildings will require electrification of heating systems through heat pump deployment.

When looking across all building typologies there is an even split between natural gas heat and electric heat. While not available within the data sets used for this analysis, we expect only a small fraction of the electrically heated building to use heat pumps at this time. The remaining heat sources of fuel oil and propane make up just over 5% of buildings. District heat is 2.1% of buildings.

Table 7. Total heating fuel usage breakdown. Note that energy and emission values represent total building energy use including non-heating end-uses.

Heating Fuel	Total EUI (kBTU/ft2)	Buildings (%)	Sq. Ft. (%)	Total Energy (%)	Fossil Energy (%)	Emissions (%)
Natural Gas	72	48.1	46.8	52.5	78.1	50.9
Electricity	55	44.3	45	38.5	14.6	41.3
Fuel Oil	61	3.9	2.7	2.6	4.3	2.8
District	82	2.1	4.4	5.6	1.8	4.2
Propane	48	1.5	1	0.8	1.2	0.8

Figure 16 and Figure 17 respectively provide total and relative frequencies for heating fuel usage by building type. When viewed as a relative comparison within each building typology, makeup of heating fuel types is evenly split once again or have more of a skewed proportion towards one or the other (Figure 17). Lodging and labs tend to use more electric heating while warehouses, mercantile, healthcare, food service, and religious assembly tend to use more natural gas.

Figure 16. Percent market share of use types with different heating fuels by number of buildings, total square feet, total on-site fossil energy use, and total energy use. The food sales use type was excluded due to insufficient data.

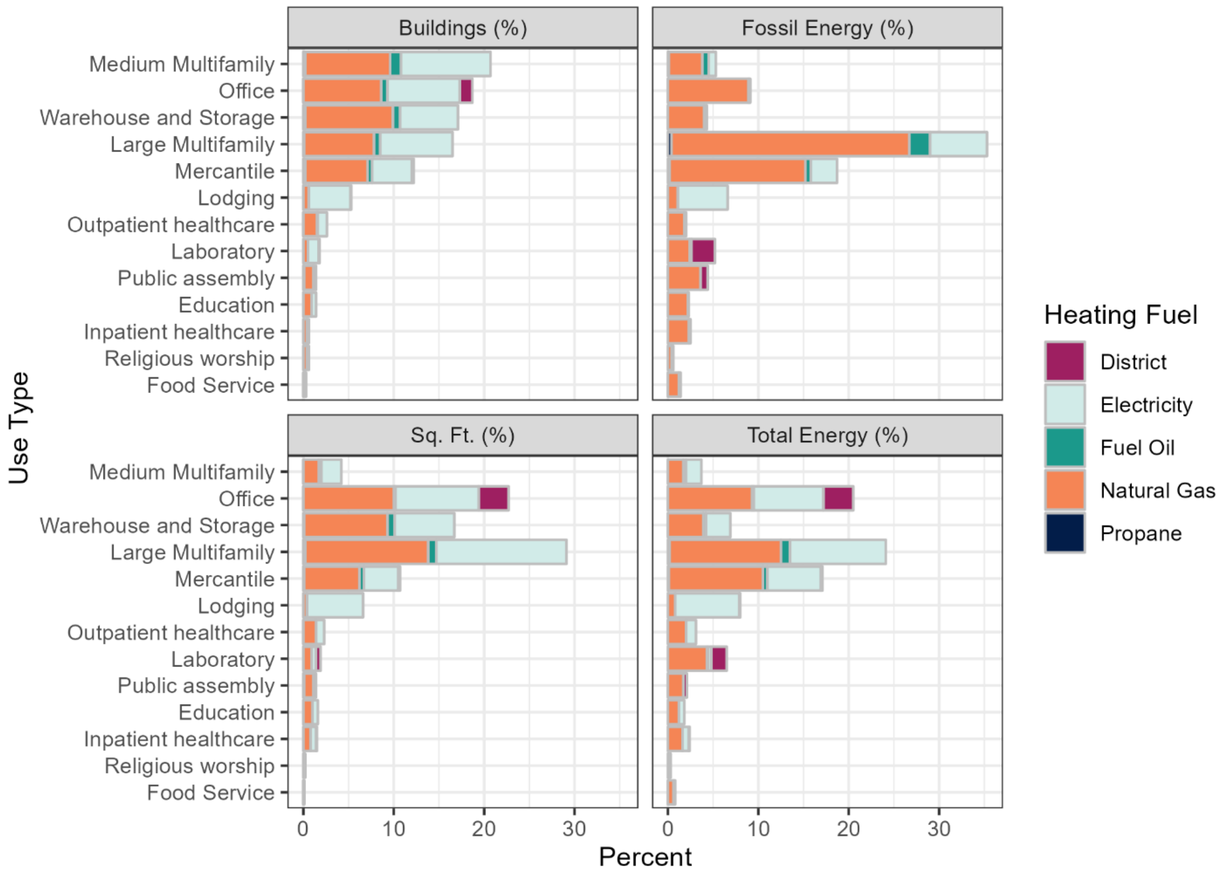
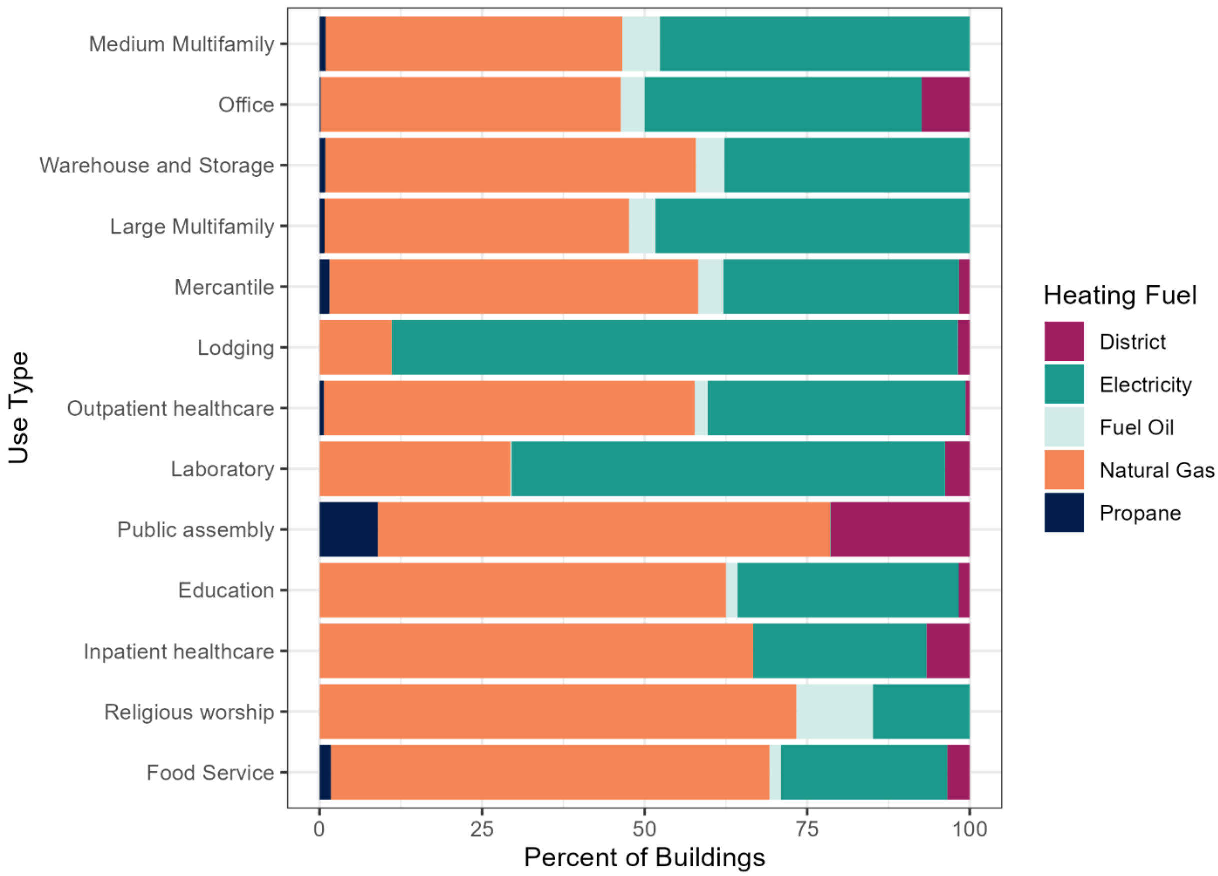


Figure 17. Percent of buildings within each use type with different primary heating fuels. Food sales was excluded due to insufficient data.



Hot Water Systems

Central vs Distributed Systems

Building domestic hot water DHW systems can be broken into three main categories: distributed systems, central systems, and both types.

Distributed systems are individual water heaters dispersed throughout a building to serve a single use or space. Often multiple water heaters are incorporated into a building plan near areas where hot water is needed. These are used in one third of buildings and have a smaller capacity than centralized systems. Distributed systems also have more readily available technology solutions for decarbonization. At the same time, many individual water heaters would need to be retrofitted as opposed to replacing a single central plant. Heat pump or tankless electric water heater solutions can be sensitive to placement and may require additional electrical infrastructure within a given building increasing the challenges with wide scale replacement.

Central Systems consolidate the hot water production into one plant serving the entire building. These systems often have distribution pumping and controls. Nearly 60% of buildings use centralized systems to serve the entire building. Large capacity central heat pump hot water heaters are emerging technologies requiring additional engineering among other considerations such as structural and space needs.

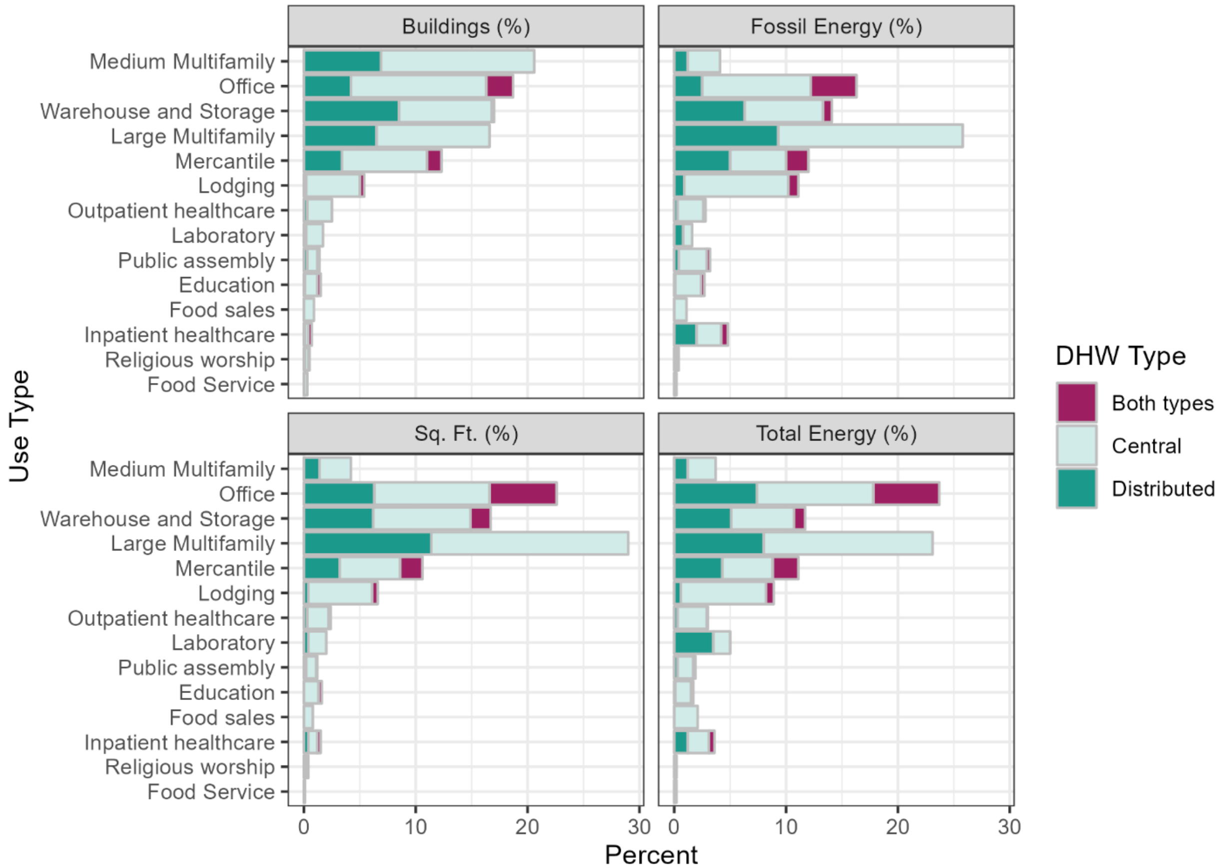
In **both types**, buildings are using a combination of multiple systems. For instance, an office building may have central hot water serving core areas while individual tenant kitchens use distributed water heaters. Note this analysis of DHW types uses only CBECS and ResStock data due to limitations with ComStock data. Some misalignment between the data sets will occur between total energy consumption and other metrics.

Table 8. Mean EUI and market share of buildings with different DHW types. Note that energy and emissions percentages represent all end uses, not just water heating.

DHW Type	Total EUI (kBTU/ft2)	Buildings (%)	Sq. Ft. (%)	Total Energy (%)	Fossil Energy (%)	Emissions (%)
Central	64	63.8	58.9	54.3	59.2	53.8
Distributed	79	31.1	29.8	34.3	29.8	34.7
Both types	69	5.1	11.3	11.4	11	11.5

Figure 18 provides four charts summarizing usage and energy consumption of different DHW systems by building type. Distributed systems are most prevalent in multifamily buildings, offices, and warehouse type spaces.

Figure 18. Percent market share of use types with different DHW types by number of buildings, total square feet, total on-site fossil energy use, and total energy use. Food sales was excluded due to insufficient data. Energy and emissions percentages represent all end uses, not just water heating.



DHW Primary Fuel

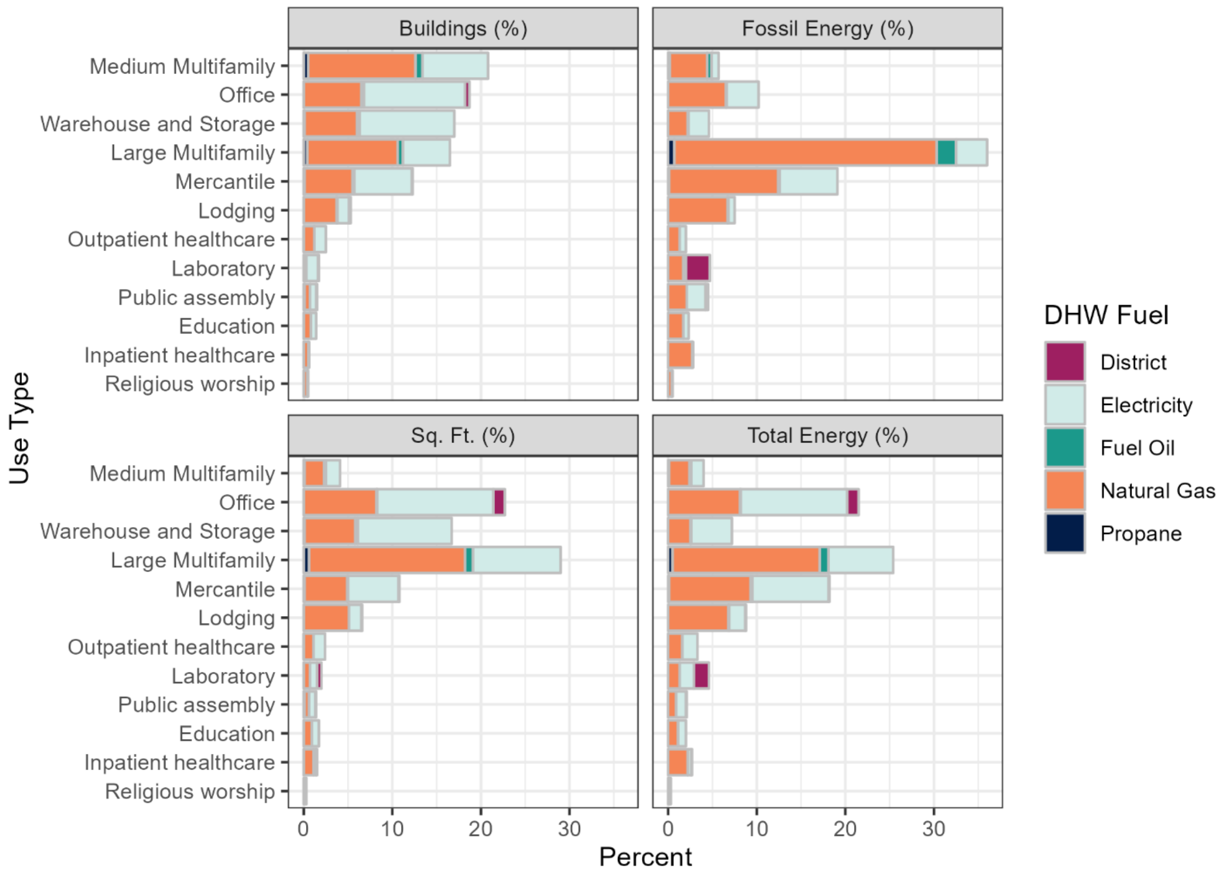
Domestic hot water heating fuel was analyzed using the combined Comstock, ResStock and CBECS data. Similar to heating fuel, there is an even mix between natural gas and electric domestic hot water systems. For a given building, heating for comfort and domestic hot water heating typically have the same fuel types. The ratios between the main fuel sources are comparable to those for heating fuel types as well.

Table 9. Mean EUI and market share of buildings with different primary DHW fuels. Note that energy and emissions percentages represent all end uses, not just water heating.

DHW Fuel	Total EUI (kBTU/ft2)	Buildings (%)	Sq. Ft. (%)	Total Energy (%)	Fossil Energy (%)	Emissions (%)
Natural Gas	67	47.9	48.4	51.8	70.8	50.2
Electricity	58	47	46.4	43	24.3	45
Fuel Oil	56	2.3	1.8	1.6	2.5	1.7
Propane	51	1.8	1.4	1.1	1.5	1.2
District	77	0.9	2.1	2.6	1	2

Figure 19 provides four charts summarizing usage and energy consumption of different DHW systems by fuel type. The most common building types multifamily, office, warehouse, and mercantile all have an even split between natural gas and electric DHW with multifamily having slightly more natural gas heater and offices and warehouse slightly more electric systems.

Figure 19. Percent market share of use types with different primary DHW fuels by number of buildings, total square feet, total on-site fossil energy use, and total energy use. Food sales was excluded due to insufficient data. Energy and emissions percentages represent all end uses, not just water heating.



BUILDING BLOCKS

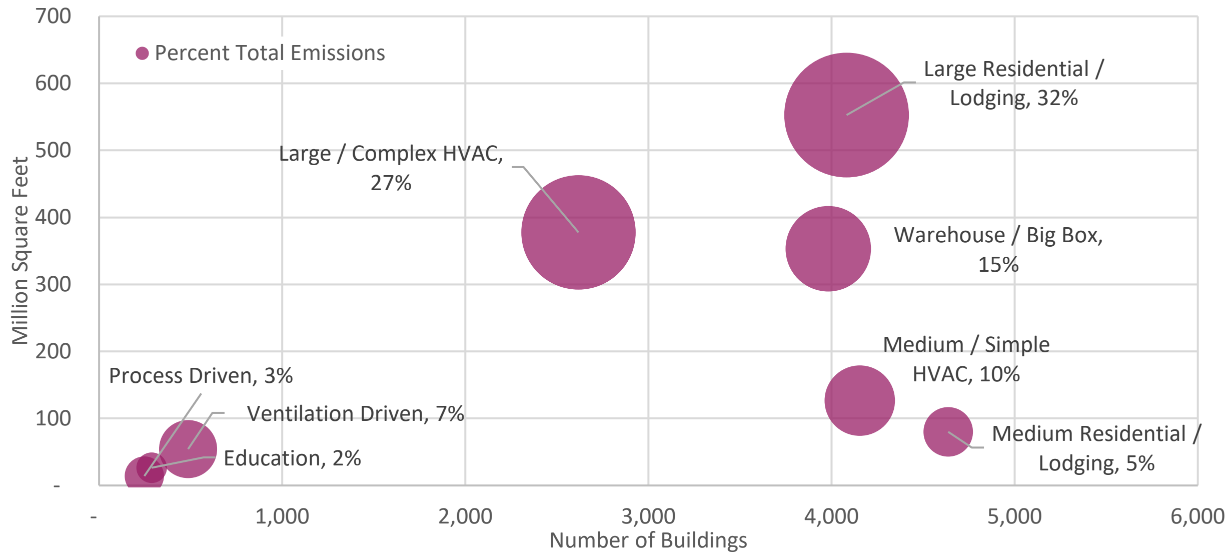
To assist in summarizing key findings, decarbonization considerations, and prioritization of building typologies for the Pilot, a series of building block categories were developed. These were informed by the preceding analysis and account for use types of the buildings, unique or shared HVAC characteristics, and other primary drivers that lend them to be categorized together. Additional information on the building blocks is provided within Appendix A.

Table 10. Descriptions of the "Building Block" typologies defined on the basis of use type, building size, and HVAC system type.

Category	Building Types	Size	Description
Medium Residential /Lodging	Multifamily	15-49 units	Mid-sized residential buildings and lodging facilities
	Lodging	20-50k ft^2	
Large Residential / Lodging	Multifamily	50+ units	Large residential buildings and lodging facilities
	Lodging	>50k ft^2	
Medium / Simple HVAC	Office	> 20k ft^2	A range of medium-sized commercial buildings typically ranging from simple to moderately complex HVAC systems and thermal zoning.
	Mercantile		
	Religious worship		
	Public assembly		
	Out-patient healthcare		
Warehouse/Big Box	Warehouse / storage	>20k ft^2	Large open space buildings typically served by multiple single zone HVAC systems
	Mercantile	>100k ft^2	
Large / Complex HVAC	Mercantile	50-100k ft^2	Large or very large commercial buildings typically with more advanced or complex HVAC systems and operational considerations than its medium sized counterpart
	Office	>50k ft^2	
	Religious worship		
	Public assembly		
	Out-patient healthcare		
Ventilation driven	Laboratory	>20k ft^2	Medium to very large buildings with complex HVAC systems which are driven by ventilation requirements
	Hospital in-patient		
Education	Education	>20k ft^2	Schools and higher education learning facilities with a range of simple to complex HVAC systems
Process Driven	Food service	>20k ft^2	Restaurants and grocery stores which typically have simple HVAC systems, but intensive process loads such as exhaust fans, cooking equipment, and refrigeration.

To support scaling considerations a bubble chart was developed for each of the building block categories comparing total counts, area, and emissions (Figure 20). Large Residential/Lodging, Large/Complex HVAC, and Warehouse/Big Box categories account for nearly 75% of the total emissions aligning with their high proportion of building area. Medium/Simple is the next typology when it comes to proportion of total emissions with 10%. While there are many medium residential buildings, they only account for 5% of the emissions. Ventilation driven buildings are few in comparison but have a high energy intensity making up 7% of the emissions.

Figure 21. Total building count vs. area vs. percent of emissions



GEOGRAPHIC CONSIDERATIONS

Massachusetts regional planning agencies provide planning, technical assistance, and coordination for local communities across the state in areas including economic development, housing, environmental stewardship, and climate change mitigation. These fourteen agencies are important both for supporting a geographically representative recruiting strategy for this Pilot and for future planning for scaling commercial building decarbonization statewide. We analyzed the distribution of the eight building block typologies across these regions to better understand how commercial buildings are distributed across the state and to gain insights into broad geographic considerations for refining these typologies and prioritizing subsets of buildings for Pilot recruitment. The location of these fourteen agencies is shown in Figure 22.

Figure 23. Areas served by the fourteen regional planning agencies in Massachusetts.

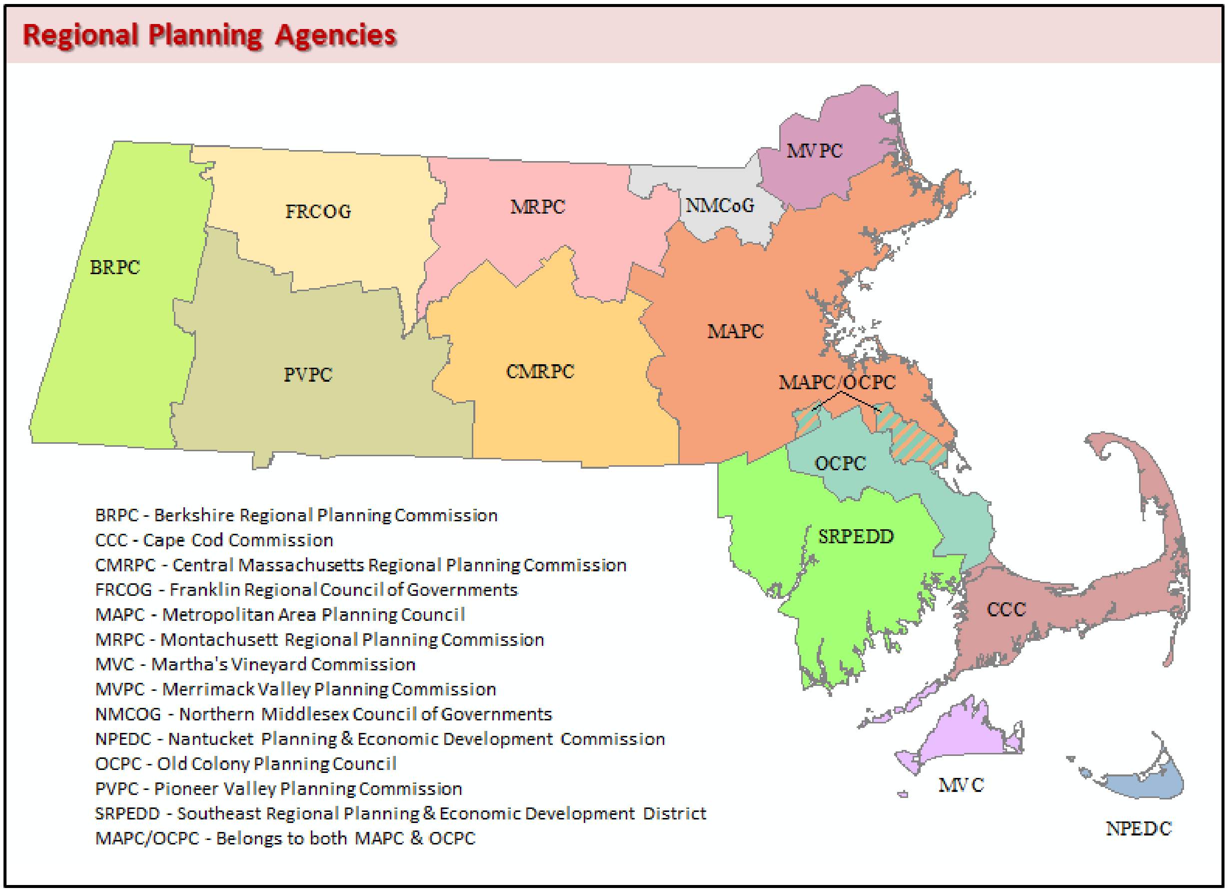
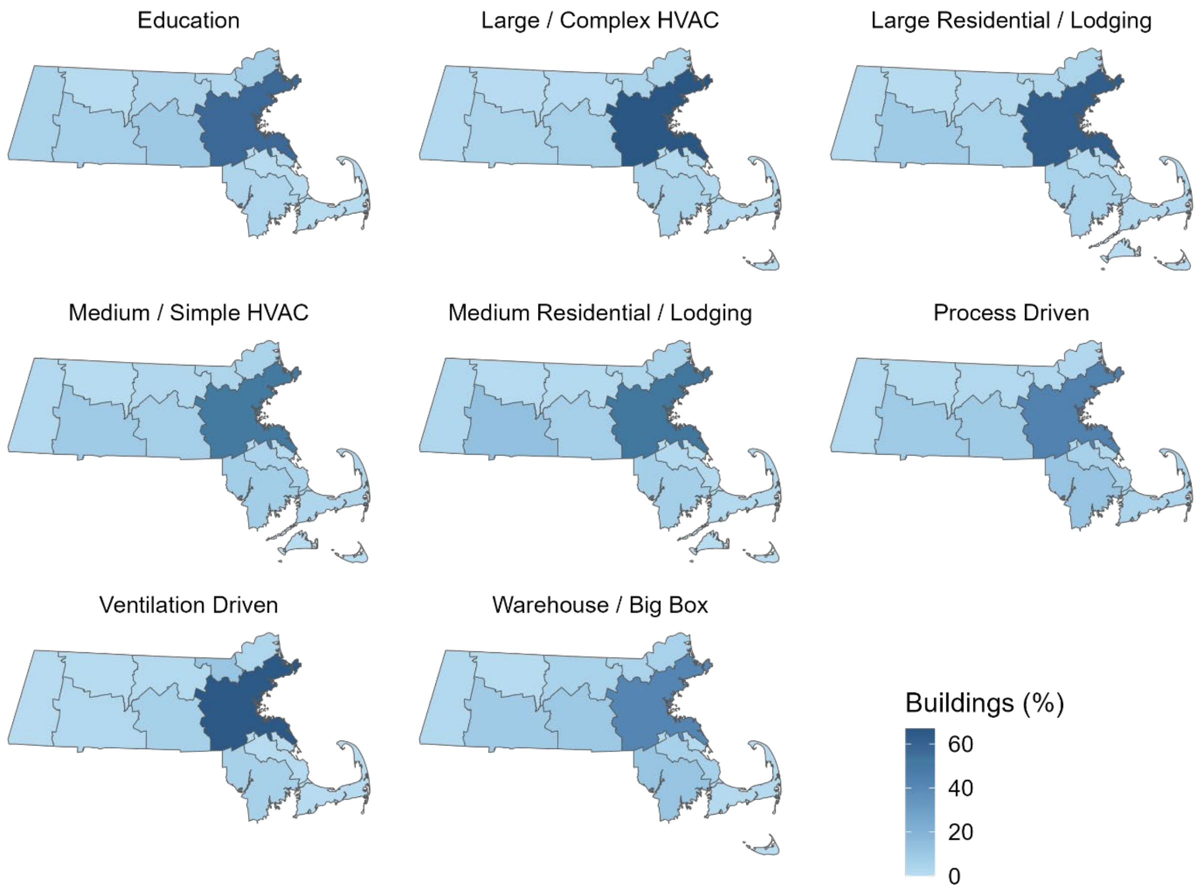


Image source: https://www.mass.gov/info-details/massgis-data-regional-planning-agencies

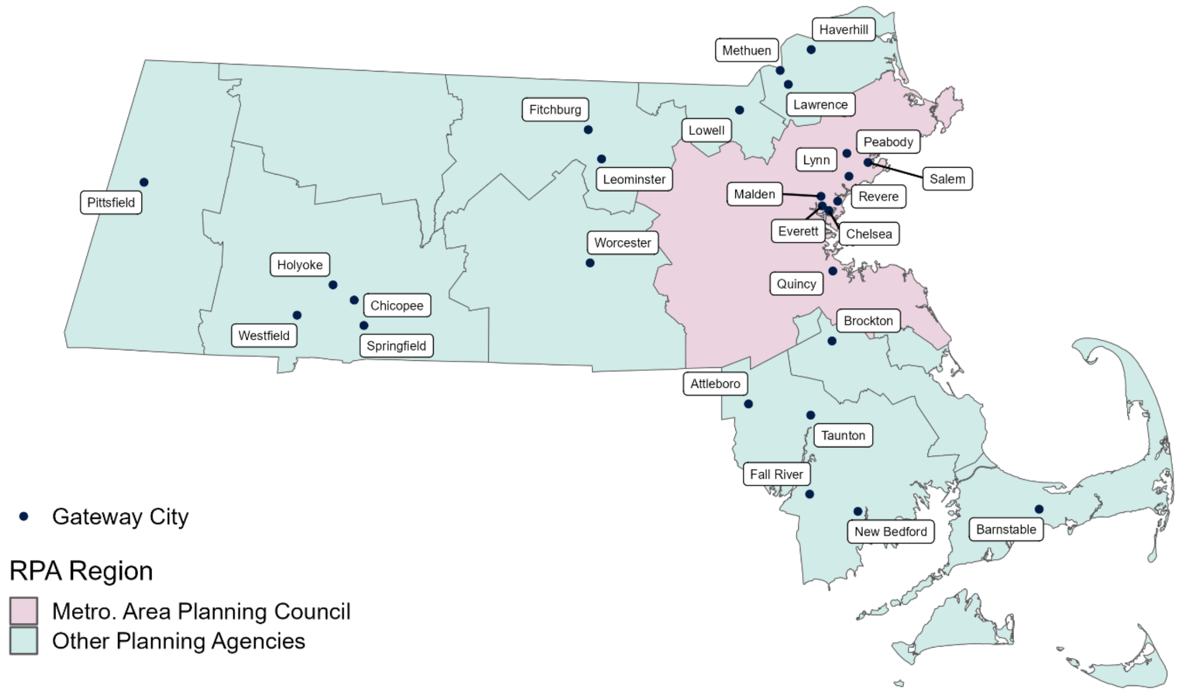
As shown in Figure 22, the buildings for each of the typologies are most concentrated in the Metropolitan Area Planning Council (MAPC) region which serves the Greater Boston Area. Although this is not a surprising result, it suggests a natural split between this region and the rest of the state which can guide recruitment and prioritization to gain high-level geographic representation in the Pilot. That said, it is worth noting that some typologies like the Process Driven and Warehouse/Big Box segments have a more even distribution across the planning agencies compared to other typologies like the Large/Complex HVAC and Ventilation Driven sectors which are highly concentrated in the Greater Boston Area.

Figure 24. Percentage of buildings within each of study building block typologies falling within the fourteen regional planning agencies.



The geographic division between the MAPC and the other agencies is shown clearly in the map below (Figure 23). Also shown are the 26 Gateway Cities, which are mid-sized metropolitan areas, mostly outside of the Boston area, that historically served as important economic hubs within their communities but recently have been the focus of statewide economic and community development efforts because of declining incomes and educational attainment. Buildings in these cities should receive special consideration in the recruitment and screening process as the decarbonization pathways may uncover obstacles and opportunities that will be broadly applicable to an important segment of the state commercial building stock.

Figure 25. Map showing the geographic divide between the Greater Boston Area served by the Metropolitan Area Planning Council and the 13 other planning councils serving the rest of the state. These regions form a natural geographic split to guide prioritization and recruitment. The locations of the 26 Gateway Cities are also indicated.



PRIORITIZATION RECOMMENDATIONS

The report provides a summary of the commercial and multifamily building stock in relation to identified key characteristics which can be used to distinguish buildings that follow common decarbonization pathways and challenges that can be better understood through this Pilot. These include building type, size, vintage, location, environmental justice considerations and HVAC and DHW systems. Using these metrics along with other market drivers such as ownership structures and capital planning considerations we can prioritize building typologies for selection.

Working with MassCEC and stakeholders, we identified three value propositions for delineating and prioritizing building typologies that support future market assistance and transformation towards Massachusetts's 2050 greenhouse gas emission reduction goals.

High-impact scaling: Some typologies have characteristics which make scaling their decarbonization to the state-wide population easier and more impactful. For example, lessons learned from decarbonizing buildings in the most common building typologies like types and HVAC systems, will naturally scale and apply broadly beyond this Pilot. Similarly, typologies with the highest emissions would have comparably greater scaled impacts. Policies targeting specific building typologies can also make impacts from the Pilot more scalable through access to grant funds or electrification requirements.

Top scaling considerations:

- Large Residential/Lodging; Large/Complex HVAC; and Warehouse/Big Box categories are the top three emissions producers and also represent the typologies with the largest square footage.
- Medium/Simple HVAC also have a considerable number of buildings and associated emissions. This category is also predominantly served by small, packaged units, the most common commercial building HVAC system.
- Medium Multifamily buildings have significant support to decarbonize in comparison to other commercial building types and therefore will not be prioritized.
- Education may be a good candidate for scaling as early adopters. Many education facilities already focus on operational energy savings, have the ability for long term planning, and public sentiment may support funding.

Environmental Justice: Special consideration should be given to understanding unique challenges and opportunities associated with decarbonizing commercial buildings in designated environmental justice (EJ) communities. This will ensure that the results of this Pilot can apply to and benefit commercial businesses and multifamily residences owned, operated by, and/or serving vulnerable populations. Evaluating the applicability of environmental justice considerations for building types requires considering multiple sources of information about buildings and communities, including EJ community designation based on state and national definitions, income, ownership, and funding/maintenance mechanisms.

Top environmental justice considerations

- Characterizing EJ building populations by the primary characteristics indicated that there is little difference between size, vintage, and HVAC systems groups between EJ and non-EJ buildings.

- Multifamily buildings are more prevalent than other building types. Lodging, offices, and warehouse spaces are considerably less prevalent.
- Ultimately EJ typology prioritization will be primarily based on outreach to building owners and key stakeholders to focus on specific sites with benefits to local communities and specific ownership types which are currently under resourced.

Applicability: To the extent possible, the recommended set of participating buildings in this Pilot should have characteristics and associated decarbonization paths that represent most medium-to-large commercial buildings in the state. This means that the set of participating typologies should include a variety of HVAC systems, ages, sizes, ownership structures, financing mechanisms, and retrofit pathways so that lessons learned from this Pilot can apply broadly to future decarbonization efforts.

Top applicability considerations

- Prioritize at least a third of buildings to have complex HVAC systems encompassing boilers, packaged multi-zone VAV systems, and DOAS solutions with both WSHP and ASHP/VRF technologies.
- Seek diversity within specific building types for the large and medium commercial categories
- Provide plans for at least one process- or kitchen-driven facility
- Enroll a variety of building vintages and construction types

PRIMARY DRIVERS OF PRIORIZIATION

The following prioritization table has been developed based on the three value propositions to assist in the outreach and enrollment of an optimized set of cohort buildings for the Pilot. Buildings are grouped by block category and labelled with specific targets for enrollment. Size ranges are generally inherent to the category. Vintages and location are provided with high, medium, and low priorities. HVAC and DHW characteristic priorities are labeled with general preference for fuel type and simple or complex characteristics. Regional and environmental justice attributes are also prioritized.

PRIORITIZATION FRAMEWORK

Category	Building Type	Target	Size	Vintage			HVAC Characteristics		DHW Characteristics		Location Priority	
				Pre 1980	1980-2004	2004+	Heating Fuel	Type	Fuel	Type	EJ Community	Non-metro
Medium Residential /Lodging	Medium multifamily	-	15-49 units	-	-	-	-	-	-	-	-	-
	Medium lodging	-	20,000-50,000	-	-	-	-	-	-	-	-	-
Large Residential / Lodging	Large multifamily	2	20,000-50,000	HIGH	MED	HIGH	Gas	Complex	Gas	Central/Dis	HIGH	MED
	Large lodging		20,000+	MED	MED	MED	Elec	PTAC	Gas/Elec	Central/Dis	LOW	MED
Warehouse/ Big box	Warehouse	2	20,000+	MED	MED	LOW	Gas	PSZ RTU	Gas/Elec	Distributed	LOW	HIGH
	Big box retail		100,000+	MED	MED	LOW	Gas	PSZ RTU	Gas/Elec	Distributed	LOW	HIGH
Medium / Simple HVAC	Office	1	20,000-50,000	LOW	MED	HIGH	Gas/Elec	Complex/ Packaged	Gas/Elec	Central/Dis	MED	HIGH
	Mercantile	1	20,000-50,000	MED	MED	MED	Gas/Elec	PSZ RTU/ Res Style Furn	Gas/Elec	Central	HIGH	MED
	Religious worship	1	20,000-50,000	HIGH	LOW	LOW	Gas	Complex/ Packaged	Gas	Central	HIGH	MED
	Public assembly		20,000-50,000	HIGH	MED	MED	Gas	Complex/ Packaged	Gas	Central	MED	MED
	Out-patient healthcare		20,000-50,000	MED	MED	MED	Gas	Complex/ Packaged	Gas	Central/Dis	MED	MED
Large / Complex HVAC	Office	1	50,000+	LOW	MED	HIGH	Gas/Elec	Complex	Gas/Elec	Central	MED	MED
	Mercantile	1	50,000-100,000	LOW	MED	MED	Gas/Elec	PSZ RTU	Gas/Elec	Distributed	MED	MED
	Religious worship	1	50,000+	HIGH	LOW	LOW	Gas	Complex/ Packaged	Gas	Central/Dis	MED	MED
	Public assembly		50,000+	HIGH	MED	MED	Gas	Complex	Gas	Central/Dis	MED	HIGH
	Out-patient healthcare	1	50,000+	MED	MED	MED	Gas	Complex/ Packaged	Gas	Central/Dis	MED	MED
Ventilation driven	Laboratory	1	50,000+	LOW	MED	HIGH	Gas	Complex	Gas	Central	LOW	LOW
	Hospital in-patient		100,000+	MED	MED	LOW	Gas	Complex	Gas	Central	MED	MED
Education	K-12 School	2	100,000+	LOW	HIGH	HIGH	Gas	Complex/ Packaged	Gas	Central	HIGH	HIGH
	Higher Ed		50,000+	MED	MED	MED	Gas	Complex	Gas	Central	MED	MED
Process Driven	Food service	1	20,000+	MED	MED	MED	Gas/Elec	PSZ RTU	Gas/Elec	Central/Dis	MED	LOW
	Grocery		20,000+	MED	HIGH	MED	Gas	PSZ RTU	Gas/Elec	Central/Dis	HIGH	MED

APPENDIX A – BUILDING BLOCK CATERGORIES

DECARBONIZATION BUILDING BLOCK

MEDIUM RESIDENTIAL AND LODGING

Mid-sized residential buildings are buildings with 15 to 50 living units. Their smaller size means smaller impact than the larger buildings, but by count these buildings make up 22% of Massachusetts building stock. Also, they are common in environmental justice communities with approximately half of the medium multifamily buildings analyzed being designated as low income. These buildings often have simple HVAC systems, making transition to electrified systems easier., In fact, 8% of these buildings already have heat pumps in place. However, 66% of these buildings have central domestic hot water systems that are difficult to electrify given the large demand of these buildings.

Decarbonization Potential

- Common building type and common in environmental justice communities.
- Simple HVAC systems are easier to decarbonize.
- Help reduce energy bills for low-income tenants and improve indoor environmental quality when electrification is combined with envelope efficiency improvements.
- Have access to several existing or planned programs and guides.

Decarbonization Challenges

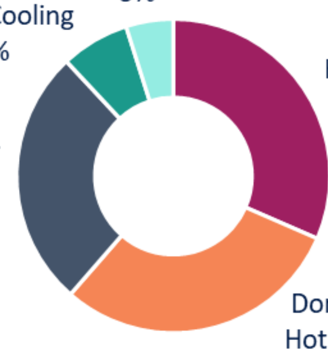
- Owners may have less access to resources for decarbonization.
- Challenges with residential landlord- tenant utility bill structure.
- 84% of buildings were built before 1980 and require upgrades to the envelope.
- Central hot water systems are difficult to electrify.
- Limited roof area for solar arrays on dense residential and lodging buildings.

MEDIUM RESIDENTIAL AND LODGING BUILDINGS

Building Block Statistics

Number of buildings	4,637	(22.6%)
Total square footage	80.0 mil	(5.0%)
Average energy use intensity, kbtu/sf/yr	71.1	
Total MA Building Energy Emissions, Tons CO_2e per year	353,783	(5.0%)

Mid-Size Multifamily Energy End Uses



Vintage	Multifamily	Lodging
Pre-1980	84.0%	40.7%
1980-2003	7.3%	35.9%
Post-2003	8.7%	23.5%

Most Common HVAC Systems	
`Residential DX Furnace	36%
Electric Baseboard and AC	28%
Boiler Radiator and AC	16%
Residential Air Source Heat Pump (ASHP)	8%
Boiler, no A/C	6%

Percent of buildings with heating fuel	Multifamily
Gas	45.6%
Electric	47.7%
Fuel Oil or Propane	6.7%
District Heating	0%
District Heating	0%

Percent of buildings with hot water fuel	Multifamily
Gas	58.2%
Electric	35.6%
Fuel Oil or Propane	6.2%

DECARBONIZATION BUILDING BLOCK

LARGE RESIDENTIAL AND LODGING

Multifamily buildings with over 50 units and lodging buildings like hotels or dormitories over 50,000 square feet are one of the most common commercial building types in Massachusetts. This block has the most emissions of the eight blocks in this report, accounting for 31% of commercial building emissions. These buildings are generally newer, with 40% of them built after 2003, and often have larger and more centralized heating, cooling, and hot water systems. They also are common in environmental justice communities with approximately half of the large multifamily buildings analyzed being designated as low income.

Decarbonization Potential

- The high number of buildings and emissions means it has the highest opportunity to decarbonize buildings in the commonwealth.
- Owners often have access to more resources than smaller multifamily buildings.
- The multifamily market is transitioning to larger developments creating more market drivers for tenant improvements and retrofit activities.

Decarbonization Challenges

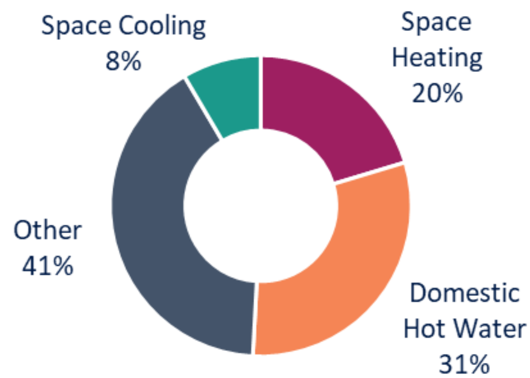
- More complex central HVAC systems like WSHPs are difficult to retrofit with electrified heating.
- Centralized DHW heat pump water heaters are still emerging as a straightforward replacement technology.
- Central and tenant electric panels and electric conduits may not be sized for new electric equipment and require upgrades.

LARGE RESIDENTIAL AND LODGING

Building Block Statistics

Number of buildings	4,082	19.9%
Total square footage	552 mil	34.9%
Average energy use intensity, kbtu/sf/yr	64.6	
Total MA Building Energy Emissions, Tons CO_2e per year	2,244,000	31.6%

Large Multifamily Energy End-Uses



Vintage	Multifamily	Lodging
Pre-1980	38.6%	40.7%
1980-2003	19.5%	35.9%
Post-2003	41.9%	23.5%

Most Common HVAC Systems	
Residential DX Furnace	39%
Electric Baseboard and AC	23%
Boiler Radiator and AC	11%
Packaged Terminal Air Conditioner	10%
Residential Air Source Heat Pump (ASHP)	9%

Percent of buildings with heating fuel	Multifamily	Lodging
Gas	46.8%	11.1%
Electric	48.3%	87.1%
Fuel Oil or Propane	4.9%	0%
District Heating	0%	1.8%

Percent of buildings with hot water heating fuel	Multifamily	Lodging
Gas	61.8%	71.2%
Electric	32.2%	25%
Fuel Oil or Propane	6.0%	0%
District Heating	0%	3.8%

DECARBONIZATION BUILDING BLOCK

WAREHOUSE AND BIG BOX BUILDINGS

Warehouses over 20,000 square feet and "big box" retail over 100,000 square feet have the lowest energy use intensity of the building blocks. However, that energy adds up since these buildings make up a large proportion of the commercial building population, resulting in over 7% of building energy emissions. Decarbonizing these buildings is easier due to simple building layouts and systems. Most of the energy is used for space heating, equipment, and lighting. New heat pump RTU technology and LED lights can lower energy use, while large solar arrays can be placed on the wide roof areas or in the large parking lots that often accompany these types of buildings.

Decarbonization Potential

- Packaged gas RTUs can be replaced by new heat pump RTUs.
- Large roof square footage is ideal for large solar arrays that can offset the low energy intensity of this building type.
- LED lighting and occupancy controls can reduce the high lighting energy use.

Decarbonization Challenges

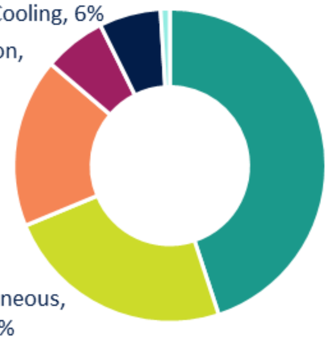
- Often has a lot of gas infrastructure for heating.
- Low energy use means low energy cost for building owners, and therefore may need more incentive to decarbonize.
- Big Box retail is more occupied than warehouses and could have additional loads like lighting and refrigeration.

WAREHOUSE AND BIG BOX BUILDINGS

Building Block Statistics

Number of buildings	3,982	19.4%
Total square footage	353.1 mil	22.3%
Average energy use intensity, kbtu/sf/yr	53.8	
Total MA Building Energy Emissions, Tons CO_2e per year	1,054,319	14.8%

Warehouse Energy End-Uses



Vintage	
Pre-1980	48.0%
1980-2003	38.8%
Post-2003	13.2%

Most Common HVAC Systems	
Residential Furnace Only	36%
Packaged Single Zone RTU Dx Elec	25%
Packaged Single Zone RTU Dx Boiler	13%
Packaged Single Zone RTU DX Gas	10%
PTHP	10%

Percent of buildings with heating fuel	Warehouse
Gas	57.0%
Electric	37.7%
Fuel Oil or Propane	5.3%
District Heating	0%

Percent of buildings with hot water heating fuel	Warehouse
Gas	28.1%
Electric	64.5%
Fuel Oil or Propane	1.0%
District Heating	6.4%

DECARBONIZATION BUILDING BLOCK

MEDIUM BUILDINGS / SIMPLE HVAC

This block consists of offices, retail, public assembly, places of worship, and outpatient healthcare buildings between 20,000 and 50,000 square feet. Although small, there are many of these buildings, and they account for 10% of commercial building energy emissions in the Commonwealth. Over half of these buildings are over 40 years old, and one in three buildings can be found in environmental justice communities. These buildings are characterized by their use of generally simple HVAC and plumbing systems, making them easier to decarbonize.

Decarbonization Potential

- Many buildings throughout Massachusetts.
- Simpler systems are easier to decarbonize.
- Buildings generally have roof space for solar arrays.

Decarbonization Challenges

- May have owners with more limited resources for decarbonization.
- Need to understand tenant-landlord relationships for upgrades to commercial tenant spaces.
- Older buildings will have poor envelope and high heating loads.

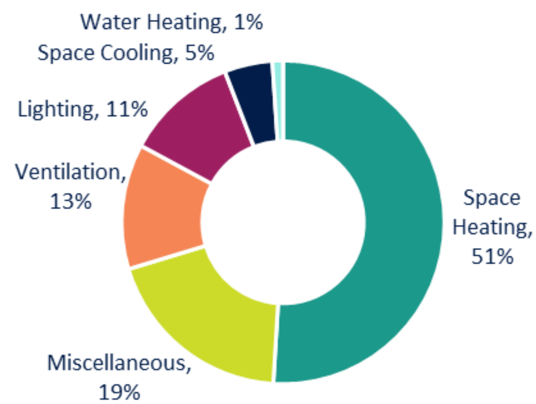
DECARBONIZATION BUILDING BLOCK

MEDIUM BUILDINGS / SIMPLE HVAC

Building Block Statistics

Number of buildings	4,154	20.3%
Total square footage	126.6 mil	20.3%
Average energy use intensity, kbtu/sf/yr	78.2	
Total MA Building Energy Emissions, Tons CO_2e per year	715,836	10.1%

Medium / Simple HVAC Building Energy End Uses



Vintage	
Pre-1980	56%
1980-2003	34%
Post-2003	10%

Most Common HVAC Systems	
Packaged Single Zone RTU Dx Elec	33%
Packaged Single Zone RTU DX Gas	31%
Packaged Single Zone RTU Dx Boiler	8%
Residential DX Furnace	6%
Packaged Multi-zone VAV Dx Gas	4%

Percent of buildings with heating fuel	
Gas	51.3%
Electric	39.1%
Fuel Oil or Propane	6.1%
District Heating	3.5%

Percent of buildings with hot water heating fuel	
Gas	38.4%
Electric	58.0%
Fuel Oil or Propane	2.6%
District Heating	0.8%

DECARBONIZATION BUILDING BLOCK

LARGE BUILDINGS / COMPLEX HVAC

Large commercial buildings, which includes office, outpatient healthcare, public assembly, and religious worship, above 50,000 square feet and retail between 50,000 and 100,000 square feet, only accounts for 12.8% of the building population, but 23.8% of the square footage. These large buildings contribute the second most building energy emissions out of the blocks. They are characterized with more variety and more complex HVAC systems and centralized hot water, which can be difficult to retrofit with electrification options. A key to decarbonizing these buildings is to address the high ventilation (fan) and heating energy.

Decarbonization Potential

- This block accounts for 26% of Commonwealth commercial building carbon emissions and presents a great opportunity to decarbonize buildings in Massachusetts.
- Owners of large buildings have access to more resources and design and construction professionals to help with decarbonization.

Decarbonization Challenges

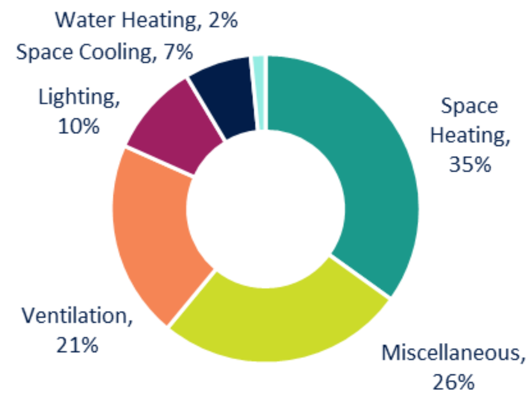
- Complex HVAC systems, such as the 31% of buildings with VAV air systems, are difficult and expensive to retrofit.
- Large buildings typically have complex envelope systems which can create challenges with retrofits.
- Taller and more dense buildings have less roof area for solar arrays.

LARGE BUILDINGS / COMPLEX HVAC

Building Block Statistics

Number of buildings	2,618	12.8%
Total square footage	377.6 mil	23.8%
Average energy use intensity, kbtu/sf/yr	82.3	
Total MA Building Energy Emissions, Tons CO_2e per year	1,889,500	26.6%

Large / Complex HVAC Building End Uses



Vintage	
Pre-1980	41%
1980-2003	43%
Post-2003	16%

Most Common HVAC Systems	
Packaged Single Zone RTU Dx Elec	25%
Packaged Single Zone RTU DX Gas	11%
Central Multizone VAV Chiller Elec	11%
Packaged Single Zone RTU Dx Boiler	10%
Packaged Multi-zone VAV Dx Boiler	8%

Percent of buildings with heating fuel	
Gas	52.2%
Electric	35.9%
Fuel Oil or Propane	1.5%
District Heating	10.4%

Percent of buildings with hot water heating fuel	
Gas	41.8%
Electric	53.9%
Fuel Oil or Propane	0.3%
District Heating	4.0%

DECARBONIZATION BUILDING BLOCK

VENTILATION-DRIVEN BUILDINGS

Ventilation-driven buildings, such as in-patient hospitals and laboratories, are defined by their need for large amounts of exhaust air and high equipment energy use. In fact, this block has the second highest energy use per square foot of all the blocks. They are also very large, with the median building size being 100,000 square feet, so despite there being less than 500 of these buildings in Massachusetts, they account for a significant proportion of emissions. Many hospitals were built before 1980, while most laboratories were built between 1980 and 2003. The age and complexity of building types mean it will be challenging to decarbonize, but these buildings represent 7% of Massachusetts commercial building emissions and an opportunity to have a significant impact even one building at a time.

Decarbonization Potential

- High energy use means decarbonization efforts will have high impact.
- Owners typically have access to resources and are incentivized to reduce their high energy costs.
- There are many ways to reduce energy use across the building.

Decarbonization Challenges

- Multiple complex systems and critical process requirements are difficult to decarbonize.
- Aging buildings have limited space for renovating systems.
- Different use-types and processes mean each building with require custom decarbonization efforts.

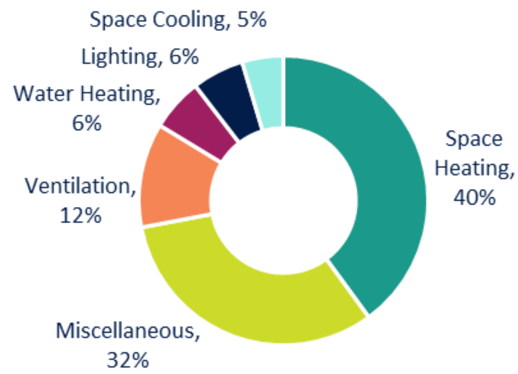
DECARBONIZATION BUILDING BLOCK

VENTILATION-DRIVEN BUILDINGS

Building Block Statistics

Number of buildings	486	2.4%
Total square footage	54.3 mil	3.4%
Average energy use intensity, kbtu/sf/yr	119.9	
Total MA Building Energy Emissions, Tons CO_2e per year	486,400	6.8%

Ventilation-Driven Building Energy End Uses



Vintage	Hospital	Laboratory
Pre-1980	64.7%	34.1%
1980-2003	25.8%	61.2%
Post-2003	9.5%	4.7%

Most Common HVAC Systems	
Central Multizone VAV, Chiller Boiler	67%
PTAC	13%
Packaged Single Zone RTU, Dx Elec	13%
Central Multizone VAV, District	7%

Percent of buildings with heating fuel	Hospital	Laboratory
Gas	66.7%	29.6%
Electric	26.7%	66.7%
Fuel Oil or Propane	0%	0%
District Heating	6.6%	3.8%

Percent of buildings with hot water heating fuel	Hospital	Laboratory
Gas	35.0%	73.3%
Electric	40.0%	20.0%
Fuel Oil or Propane	0%	0%
District Heating	25%	6.7%

DECARBONIZATION BUILDING BLOCK

EDUCATION BUILDINGS

Although schools account for just under 2% of Massachusetts buildings that are over 20,000 square feet, they are an unique building type for decarbonization. Approximately 70% of these buildings in Massachusetts were built before 1980, meaning these buildings are likely to require new equipment and will likely also require window and insulation upgrades. These buildings are more inclined to have complex HVAC systems that present challenges for electrification, but many have simple packaged units with reheat. Decarbonization is also an opportunity to improve learning environments with better indoor air quality. It is also an opportunity to make advancements in thermal and acoustic comfort, while passing lessons in energy efficiency and sustainability onto young students.

Decarbonization Potential

- Aging education buildings represent opportunity for energy efficiency improvements.
- Private educational institutions often has resources and public backing to act as early adopters for new technology and applications.
- There are many guides to net-zero energy and decarbonization of schools.
- Improvements to buildings also lead to improved learning environments.
- Many school districts and institutions of higher education already have sustainability or energy goals.

Decarbonization Challenges

- Older buildings require upgrades to building envelope and windows.
- Complex HVAC systems require careful design to electrify heating systems.
- Older buildings may not have air conditioning or ventilation.

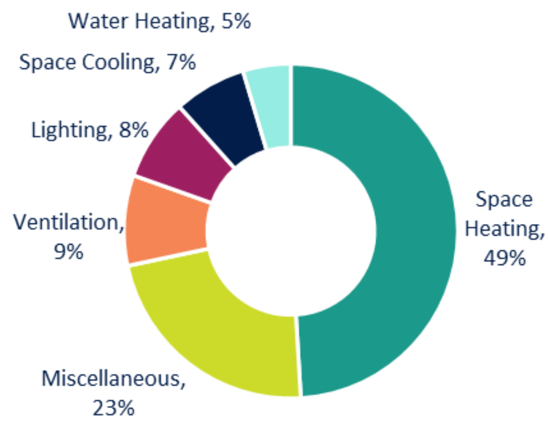
DECARBONIZATION BUILDING BLOCK

EDUCATION BUILDINGS

Building Block Statistics

Number of buildings	287	(1.4%)
Total square footage	26.6 mil	(1.7%)
Average energy use intensity, kbtu/sf/yr	73.3	
Total MA Building Energy Emissions, Tons CO_2e per year	134,000	(1.9%)

Education Building Energy End Uses



Vintage	
Pre-1980	80.1%
1980-2003	14.7%
Post-2003	5.2%

Most Common HVAC Systems	
Packaged Single Zone RTU Dx Boiler	35%
Packaged Single Zone RTU Dx Elec	19%
Residential DX Furnace	10%
Packaged Multi-zone VAV Dx Boiler	10%
Central Multizone VAV Chiller Boiler	6%

Percent of buildings with heating fuel	
Gas	62.5%
Electric	34.0%
Fuel Oil or Propane	1.8%
District Heating	1.7%
DISTRICT HEATING	**0%**

Percent of buildings with hot water heating fuel	
Gas	57.1%
Electric	42.9%
Fuel Oil or Propane	0%

DECARBONIZATION BUILDING BLOCK

PROCESS-DRIVEN BUILDINGS (FOOD SERVICE AND SALES)

These buildings consist of grocery stores and restaurants over 20,000 square feet. These buildings are characterized by their high cooking, equipment, refrigeration, and fan energy loads. They have the highest energy use intensity of all commercial buildings, although there are not many of these buildings over 20,000 square feet. Decarbonizing these buildings will be challenging as electrifying cooking and process loads at scale is still developing.

Decarbonization Potential

- These buildings have very high use intensity and often require fossil fuels for cooking and heating.
- Typically have simple heating and cooling systems.

Decarbonization Challenges

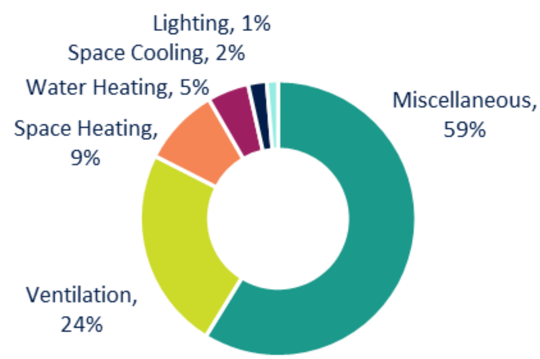
- Electrified commercial cooking technology is still developing and will be difficult to reduce in the short term.
- High refrigeration loads are 24/7 energy consumers and difficult to offset.
- These buildings typically operate with tight profit margins, and owners may not have access to additional capital.
- Limited roof area for solar compared to high energy use intensity means energy will need to be offset by off-site renewable energy.

DECARBONIZATION BUILDING BLOCK

PROCESS-DRIVEN BUILDINGS (FOOD SERVICE AND SALES)

Building Block Statistics

Number of buildings	247	1.2%
Total square footage	14.1 mil	0.9%
Average energy use intensity, kbtu/sf/yr	296.3	
Total MA Building Energy Emissions, Tons CO_2e per year	222,700	3.1%



Vintage	
Pre-1980	25.80%
1980-2003	41.30%
Post-2003	32.80%

Most Common HVAC Systems	
Packaged Single Zone RTU DX Gas	33%
Packaged Single Zone RTU Dx Elec	26%
Residential DX Furnace	21%
Packaged Single Zone RTU Dx Boiler	17%
Central Multizone VAV District	3%

Percent of buildings with heating fuel	
Gas	67.5%
Electric	25.6%
Fuel Oil or Propane	3.4%
District Heating	3.5%

Percent of buildings with hot water heating fuel	
Gas	64.0%
Electric	30.8%
Fuel Oil or Propane	1.7%
District Heating	3.5%