Building Electrification Institute

CITIES DRIVING CHANGE

Boston Multifamily Housing Stock Analysis

Completed February 2020

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Multifamily Housing Stock Analysis | Overview

Background and Summary of Project

Boston began working with the Building Electrification Institute (BEI) in 2020 as a partner through the Bloomberg American Cities Climate Challenge. Buildings account for over 70% of Boston's greenhouse gas (GHG) emissions, and achieving the City's goal of carbon neutrality will require retrofitting and electrifying at least 80 percent of existing buildings.

To support the development of an electrification strategy for multifamily buildings, BEI and its consultant, The Cadmus Group, developed an inventory of all multifamily buildings in Boston and analyzed retrofit opportunities for this building stock. Using available data, BEI grouped Boston's multifamily buildings into common typologies and identified potential envelope and electrification retrofits for these typologies. BEI also assessed building ownership and decision-making indicators and citywide social vulnerabilities to help inform potential future program development needs for Boston's multifamily buildings.

Multifamily Housing Stock Analysis | Objectives

The purpose of the Multifamily Housing Stock Analysis was to:

- Identify potential envelope and electrification retrofit packages across Boston's multifamily buildings to better understand the prevalence of these opportunities in Boston.*
- Assess ownership, decision-making, and social vulnerability indicators to help inform potential program design and approaches for multifamily retrofits.
- Identify data gaps that prevent identification of potential retrofits in buildings.

The deliverables for this analysis included:

- A parcel-level inventory of Boston's multifamily buildings in Excel format.
- The following slide deck with data visualizations and key findings from the project team's analysis of the building inventory.

Multifamily Housing Stock Analysis | Approach

1) Compile data from various sources into a single, parcel-level dataset

First, the BEI team **aggregated datasets from the the City, local utilities, and the American Census Bureau into a single dataset** for all multifamily buildings in Boston, aggregated at the parcel (or property) level.

2) Assign building typologies based on common characteristics

The team then **assigned each parcel record to a specific multifamily building typology** based on building use type, vintage, and number of units.

3) Identify envelope and heat pump retrofit opportunities

Where data was available, the team **identified potential electrification retrofit opportunities. Envelope upgrade opportunities were included** due to Boston's cold climate, since these improvements could help improve the cost-effectiveness of the retrofits (however, economics were not analyzed for this project).

4) Layer on additional indicators

Finally, the team **used City and Census Tract data to evaluate ownership, decision-making, and social vulnerability indicators** that could help inform future program and policy design.

Notes on our approach: *This analysis is intended to inform the potential for program or policy design/planning efforts only; retrofits for any specific building should be evaluated on-site by a professional for feasibility and applicability. Additionally, this analysis does assess full retrofit economics.*

Multifamily Housing Stock Analysis | Datasets

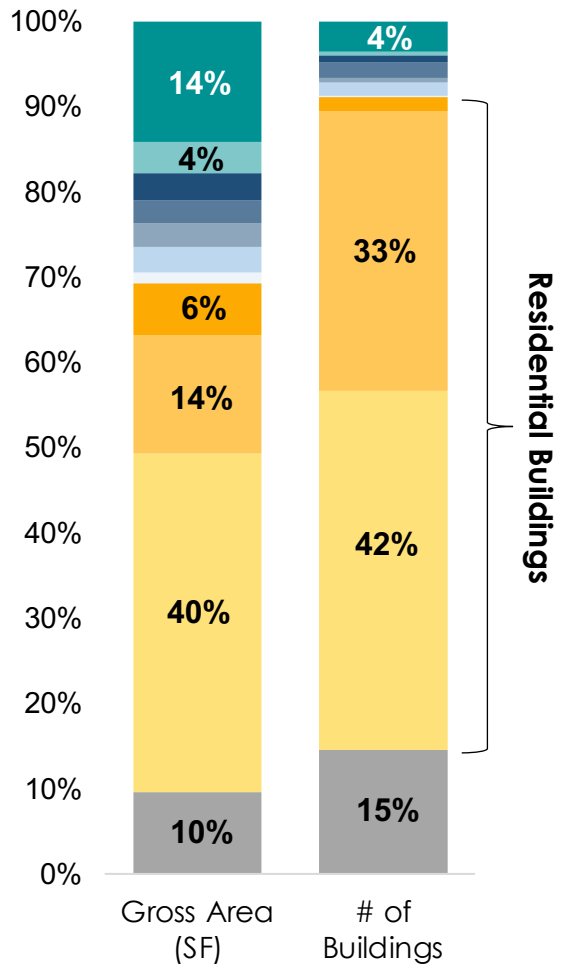
BEI used the following datasets for the Multifamily Housing Stock Analysis:

Dataset	Source*	Geography	Total # of Records	Match Rate with Parcel Data
Parcels (2017)	City of Boston, Boston Maps	Parcel	98,930	Matched against
Building Footprints	City of Boston, Boston Maps	Buildings	121,056	Not matched with parcels but used for geospatial analysis
Tax Assessor Data (2019)	City of Boston, Assessing Department	Parcel, address, unit	172,108	99.3%
Boston Apt Unit Counts (2019)	City of Boston, Assessing Department	Parcel, address	4,771	99.2%
Eversource Multi-Family Electric Resistance Heating	Eversource Energy	Parcel, address, unit	939	79.2%
Income-Restricted Housing Data (2018)	City of Boston, Department of Neighborhood Development	Parcel, address	2,775	97.9%
Building Permits (General)	City of Boston, Inspectional Services Department	Parcel, address	414,629	98.0%
Building Permits (in Historic/Landmark Buildings)	City of Boston, Inspectional Services Department	Address	60,827	98.0%
Historic Districts	City of Boston, Landmarks Commission	Historic Districts	24	100%
Landmarks	City of Boston, Landmarks Commission	Landmark Districts	170	100%
Multiple Listing Service (MLS)	City of Boston, Assessing Department	Parcel, address, unit	2,299	37.5%
MassCEC Mass Save Program Data (up to March 2015)	Massachusetts Clean Energy Center	Parcel, address, unit	794	39.9%
Boston Building Energy Reporting and Disclosure Ordinance (BERDO) Data (2018)	City of Boston, Department of the Environment	Parcel, address, unit	1,596	65.1%
Social Vulnerability Indicators	U.S. Census Bureau, Climate Ready Boston Social Vulnerability	Census Tract	1,478 (tracts)	100%

*Datasets without hyperlinks are from sources that are not publicly available.

Multifamily Housing Stock Analysis | Building Typologies

Boston Buildings – Citywide



Building Use Type	Building Gross Area (SF)	Number of Buildings
Office	92,102,017	3,291
Medical/Lab/Production	23,946,072	392
Convention/Assembly	20,960,195	760
Retail/Supermarket/ Restaurant	17,224,086	1,723
School/Fire/Police/Worship	18,552,705	462
Garage/Warehouse	19,261,561	1,502
Hotel	8,509,334	83
Residential (Mixed-Use)	39,535,704	1,585
Single Family	90,632,362	30,555
Multifamily	259,339,384	39,220
Vacant/Blank	62,864,146	13,507
Total	**652,927,566**	**93,080**

There are over 90,000 buildings in Boston, accounting for more than 650 million square feet of space.

Residential buildings account for:

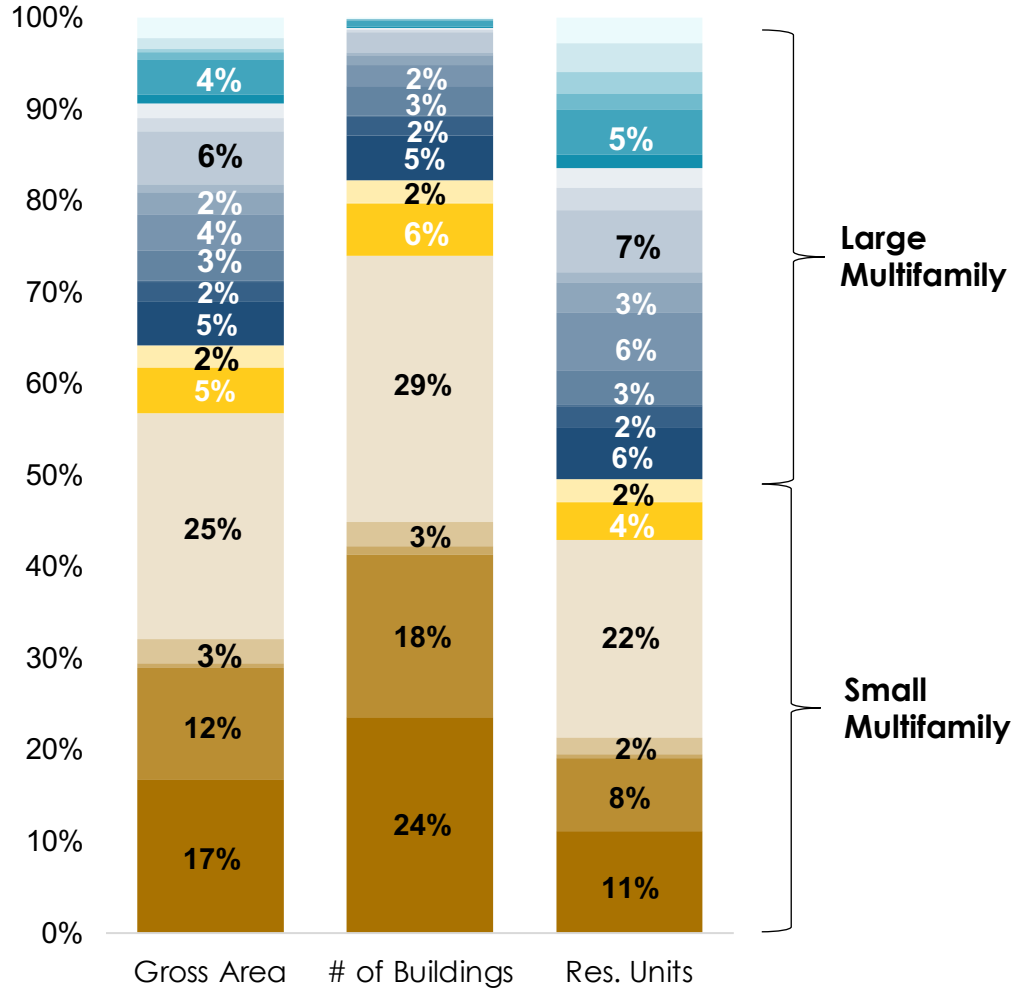
- 80% of Boston's buildings
- 60% of the built square footage

Multifamily buildings (residential buildings with 2 or more units) account for:

- 42% of Boston's buildings
- 40% of the built square footage

Multifamily Housing Stock Analysis | Multifamily Typologies

Multifamily Buildings in Boston



Building Typology	Gross Area	# of Bldgs	Res. Units
1) Multifamily (>=100 units), post-1980	5,755,727	49	5,113
2) Multifamily (>=100 units), 1951-1980	3,088,884	33	5,802
3) Multifamily (>=100 units), 1915-1950	1,001,564	14	4,351
4) Multifamily (>=100 units), pre-1915	2,212,267	55	3,219
5) Multifamily (31-99 units), post-1980	9,693,974	226	8,837
6) Multifamily (31-99 units), 1951-1980	2,616,339	59	2,699
7) Multifamily (31-99 units), 1915-1950	4,159,557	87	4,067
8) Multifamily (31-99 units), pre-1915	3,842,897	97	4,358
9) Multifamily (7-30 units), post-1980	14,919,509	880	12,464
10) Multifamily (7-30 units), 1951-1980	2,158,725	116	2,092
11) Multifamily (7-30 units), 1915-1950	6,340,928	411	6,003
12) Multifamily (7-30 units), pre-1915	10,264,683	898	11,422
13) Multifamily (4-6 units), post-1980	8,537,470	1,250	6,885
14) Multifamily (4-6 units), 1951-1980	377,889	61	347
15) Multifamily (4-6 units), 1915-1950	5,384,373	794	4,276
16) Multifamily (4-6 units), pre-1915	12,525,441	1,918	10,314
17)Multifamily (3 units), post-1980	6,136,778	960	4,455
18) Multifamily (3 units), 1951-1980	190,604	38	141
19) Multifamily (3 units), 1915-1950	12,916,942	2,220	7,485
20) Multifamily (3 units), pre-1915	63,948,397	11,350	39,492
21) Multifamily (2 units), post-1980	6,762,866	1,037	3,318
22) Multifamily (2 units), 1951-1980	1,375,464	376	816
23) Multifamily (2 units), 1915-1950	31,584,230	6,915	14,584
24) Multifamily (2 units), pre-1915	43,482,008	9,225	20,344
(blank)	61,868	151	696
Total	**259,339,384**	**39,220**	**183,580**

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Multifamily Envelope Retrofits

Opportunities for envelope retrofits are identified using building-level data on roof type, heating system type, exterior finish, building height, and historic buildings/landmarks.

Envelope Indicators

Data Indicator	Description/Categories	% of Small Multifamily Buildings (2-3 Units) with Values	% of Large Multifamily Buildings (4+ Units) with Values
Roof Type	Attics (Gable, Hip, Gambrel, Mansard), Flat, Other, Blank	85.8%	0.04%
Heating System Type	Electric, Forced Air, Heat Pump, Space Heater, Hot Water, Other, None	100%	40.0%
Exterior Finish	Asbestos, Mass (Brick/Stone, Cement Board, Concrete, Asphalt, Stucco), Non-Mass (Frame/Clapboard, Vinyl, Aluminum, Brick/Stone Veneer, Wood, Shake). Glass, Other	100%	37.7%
Height	Number of floors	100%	97%
Historic/ Landmark	Indicate whether property is in a landmarks and/or historic district	100%	100%

Data indicator sources: Tax assessor data, Eversource program data, MLS data, MassCEC data, and Historic & Landmark District GIS data

Multifamily Envelope Retrofits

Potential envelope retrofit measures are organized into five categories.

Envelope Retrofit Categories

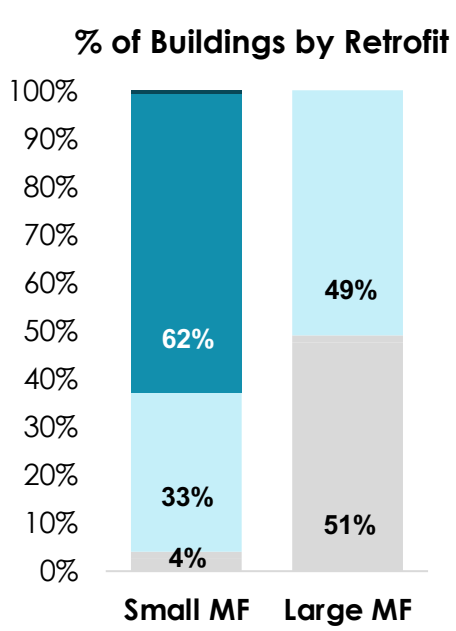
Category	Retrofits
Standard Envelope Retrofit*	• Air Sealing/Weather-stripping • Window Upgrades at the Time of Replacement • Insulate Rim Joist
Attic/Roof Retrofit	• Insulate Attic • Interior Insulation in Converted Attic • Exterior Roof Insulation
Heating Distribution Insulation**	• Insulate Exposed Pipes • Insulate Exposed Ducts
Wall Retrofit	• Interior Blown/Spray Insulation • Interior Wall Insulation Board • Insulate Behind Spandrel • Exterior Wall Insulation at Time of Replacement • Exterior Wall Insulation • Consult Professional (asbestos may be present)

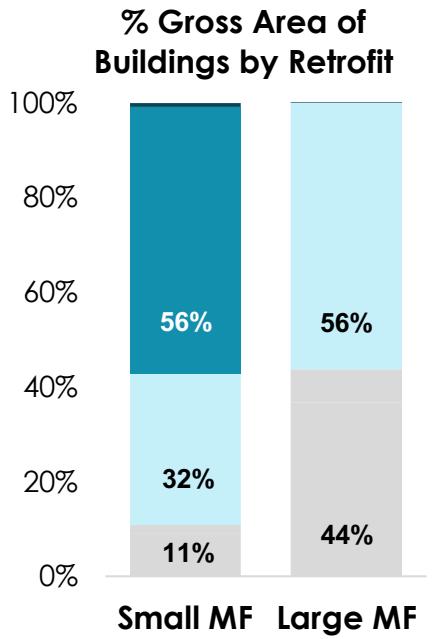
*All buildings are assumed to have the potential for a standard envelope retrofit.
**While insulating heating distribution is not actually considered part of the “envelope” it was included in this analysis since this data was available.
See additional details on these indicators in the Appendix.

Multifamily Envelope Retrofits | Attic/Roof Retrofit

Attic/Roof Insulation Opportunities

- In small multifamily buildings, there appear to be significant opportunities to insulate attics.
- Larger multifamily buildings are more likely have flat roofs, making exterior roof insulation a more common retrofit opportunity, although the high proportion of buildings that are envelope data limits the ability to identify retrofits.





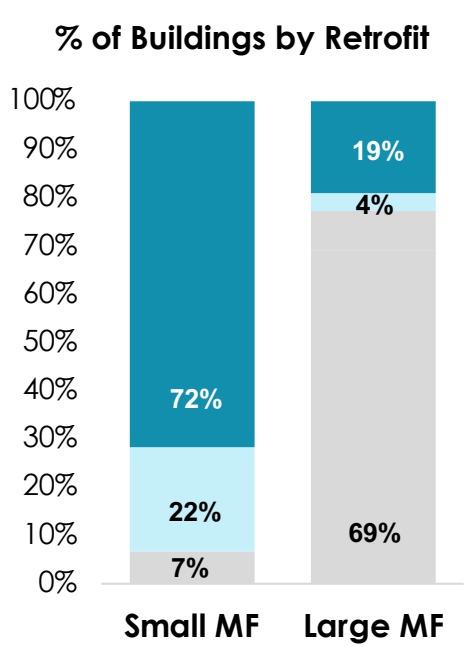
		# of Buildings		Gross Area of Buildings (SF)	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	Insulate Converted Attic	197	---	1,364,958	---
	Insulate Attic	20,033	---	93,958,398	---
	Exterior Roof Insulation	10,580	3,543	53,046,556	52,256,077
Unknown Potential	Missing Roof Type Data*	860	3,307	15,055,858	34,133,046
	Unknown Retrofit Potential	451	98	2,971,519	6,476,540

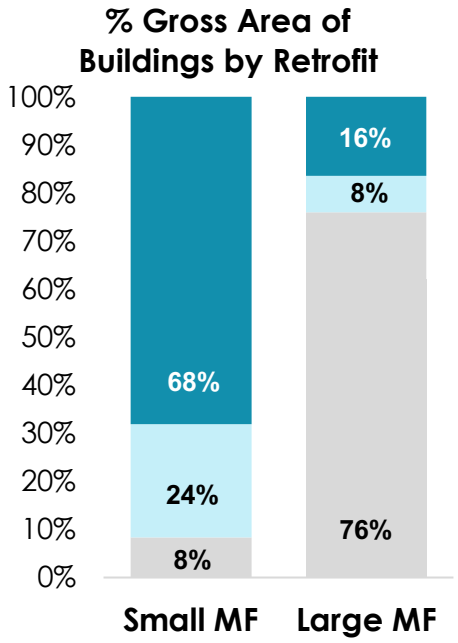
Notes on Methodology: Buildings with an attic have the potential to insulate the attic, while buildings with a flat roof were identified has having the opportunity for exterior roof insulation. Multifamily buildings 4 stories and above were assumed to have flat roofs if missing roof data. The data evaluated indicates that there are few converted attics in small multifamily properties, although anecdotally converted attics are common. This should be further verified and updated as needed.

Multifamily Envelope Retrofits | Heating Distribution Retrofit

Heating Distribution Insulation Opportunities

- A significant majority of multifamily buildings would benefit from insulating pipes. A smaller portion would benefit from insulating heating ducts.
- The significant number of large multifamily buildings that are missing heating system data limits the ability to identify retrofits.





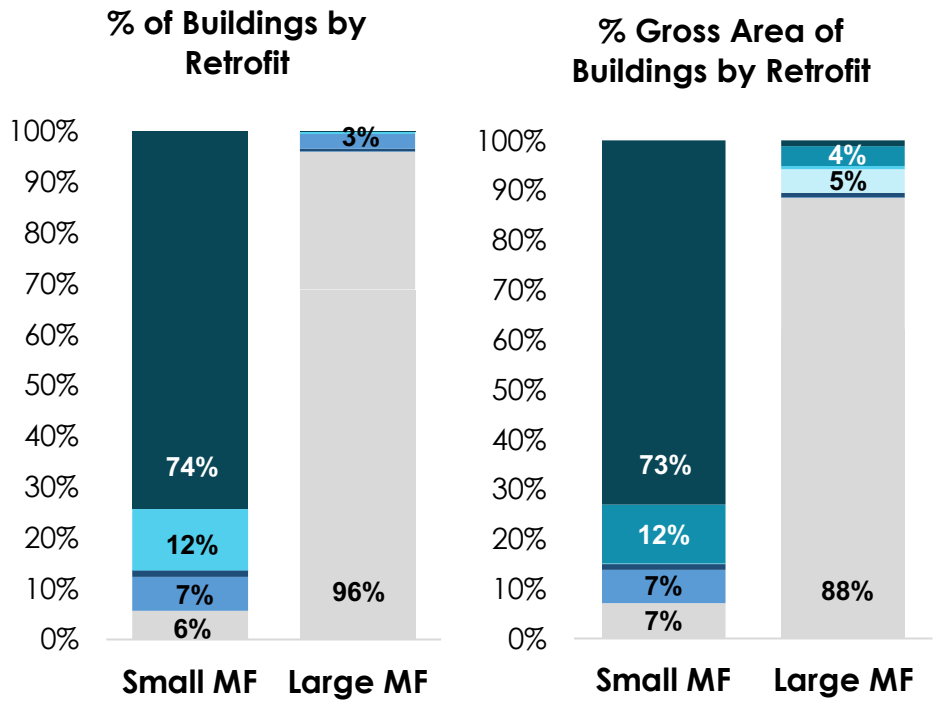
		# of Buildings		Gross Area of Buildings	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	Insulate Exposed Pipes	23,048	1,320	113,387,922	15,213,331
	Insulate Exposed Ducts	6,924	259	39,185,171	7,100,797
Unknown Potential	Missing Heat Data	1	4,793		57,612,987
	Unknown Retrofit Potential	2,148	576	13,824,196	12,953,112

Notes on Methodology: The types of heating insulation is determined based on building vintage (whether the building was built before 2000) and/or whether the building and has the presence of ducts or pipes.

Multifamily Envelope Retrofits | Wall Retrofit

Wall Retrofit Opportunities

- A significant number of small multifamily buildings have potential for spray or blown-in insulation. A smaller number have the potential for wall board insulation and other types of wall insulation.
- The significant number of large multifamily buildings that are missing data limits the ability to further identify retrofits.

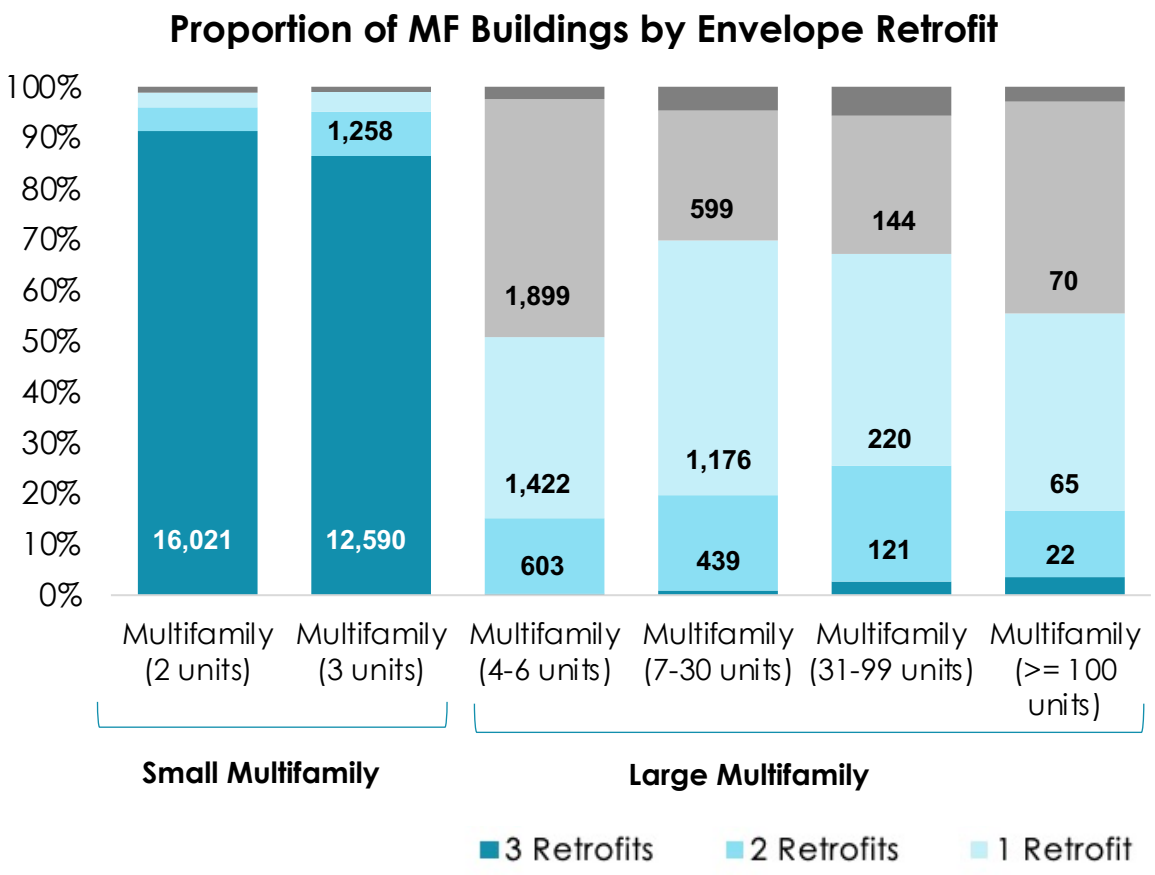


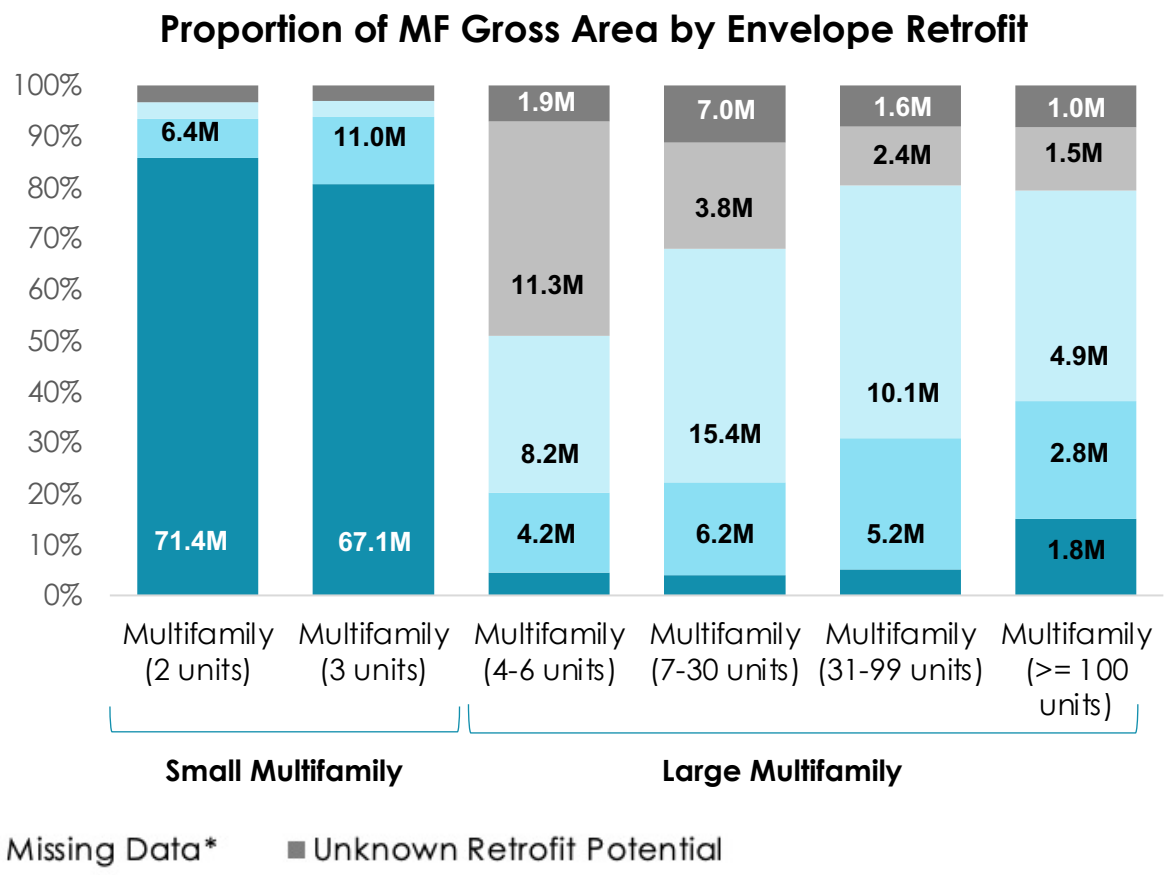
		# of Buildings		Gross Area of Buildings	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	Interior Blown/Spray Insulation	23,869	5	121,591,119	1,023,425
	Interior Wall Insulation Board	3,875	28	19,711,541	3,757,091
	Insulate Behind Spandrel	1	1	12,357	622,578
	Exterior Wall Insulation	20	202	152,266	4,440,928
	Exterior Wall Insultation at Time of Replacement	395	34	2,040,422	834,351
	Consult Professional (Asbestos)	2,144	8	10,975,420	65,894
Unknown Potential	Missing Wall Data	---	4,785	---	57,612,979
	Unknown Retrofit Potential	1,817	1,885	11,914,,164	24,522,981

Multifamily Envelope Retrofits | Envelope Packages

Envelope Package Opportunities

- A significant number of multifamily buildings have the potential for two or more envelope retrofits.





3 Retrofits | 2 Retrofits | 1 Retrofit | Missing Data* | Unknown Retrofit Potential

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Notes on Methodology: Envelope packages reflect all high potential envelope retrofits for each building, including attic/roof insulation, heating distribution insulation, wall retrofits, and/or standard retrofit opportunities.

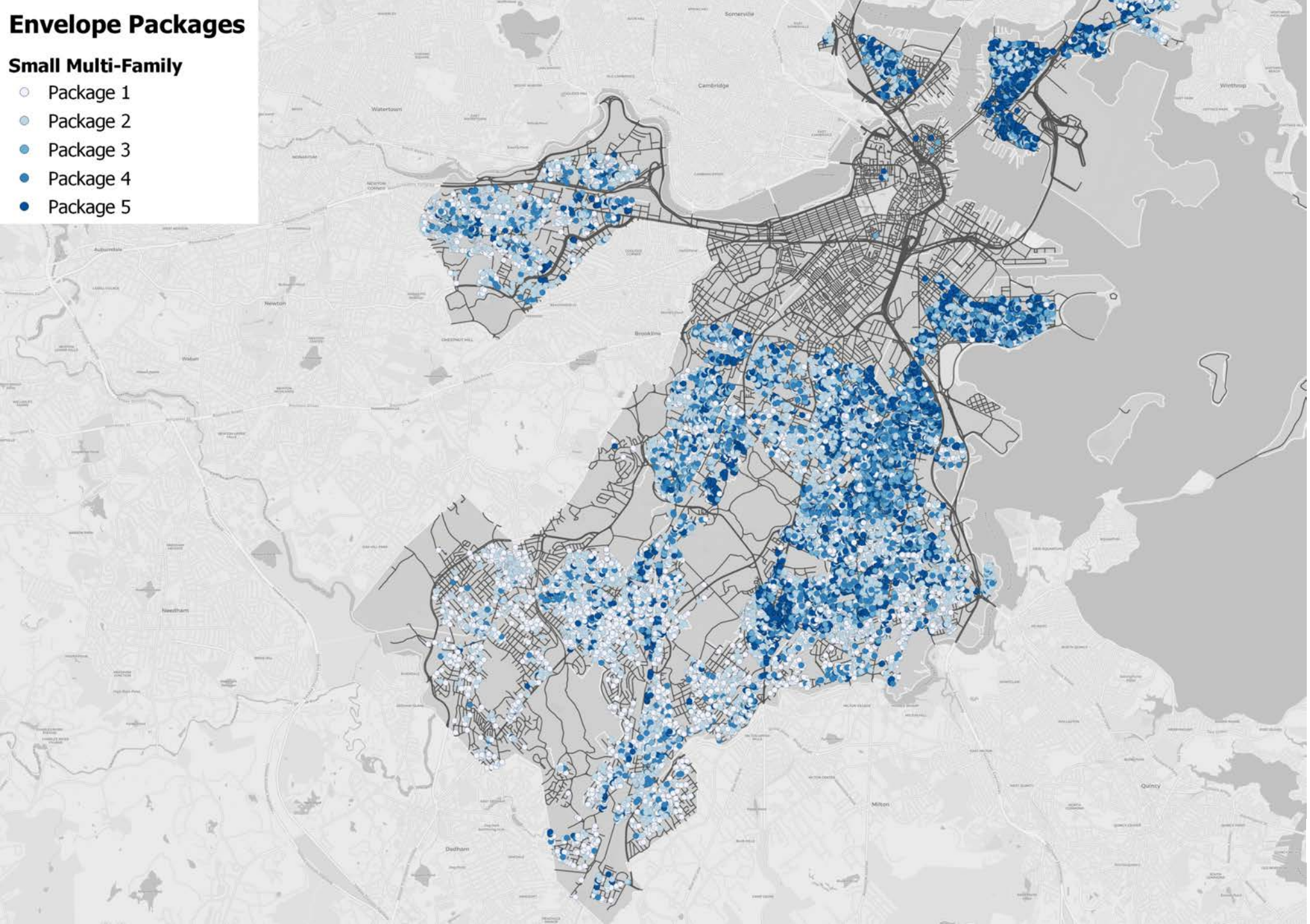
Envelope Retrofits | Envelope Packages

#	Top 5 Small Multifamily High Potential Envelope Retrofit Packages	# of buildings (% of Small MF buildings)	Gross area (% of Small MF Area)
1	Insulate attic; Insulate exposed pipes; Add blown/spray insulation to interior walls	12,482 (39%)	58.7M (35%)
2	Add exterior roof insulation; Insulate exposed pipes; Add blown/spray insulation to interior walls	5,095 (16%)	25.6M (15%)
3	Insulate attic; Insulate exposed ducts; Add blown/spray insulation to interior walls	3,301 (10%)	15.5M (9%)
4	Add exterior roof insulation; Insulate exposed ducts; Add blown/spray insulation to interior walls	2,001 (6%)	10.1M (6%)
5	Insulate attic; Insulate exposed pipes; Add insulation board on to interior walls	1,582 (5%)	7.4M (4%)
	Total for Top 5 Packages	**24,461 (76%)**	**117.8M (71%)**

#	Top 5 Large Multifamily High Potential Envelope Retrofit Packages	# of buildings (% of Large MF buildings)	Gross area (% of Small MF Area)
1	Add exterior roof insulation	2,462 (35%)	33.2M (35%)
2	Add exterior roof insulation; Insulate exposed pipes	855 (12%)	8.6M (9%)
3	Insulate exposed pipes	319 (5%)	2.4M (3%)
4	Add exterior roof insulation; Insulate exposed ducts	131 (2%)	2.1M (2%)
5	Insulate exposed pipes; Add exterior wall insulation	84 (1%)	2.0M (2%)
	Total for Top 5 Packages	**3,861 (55%)**	**46.5M (50%)**

The top 5 envelope retrofit packages account for over 50% of small and large multifamily buildings.

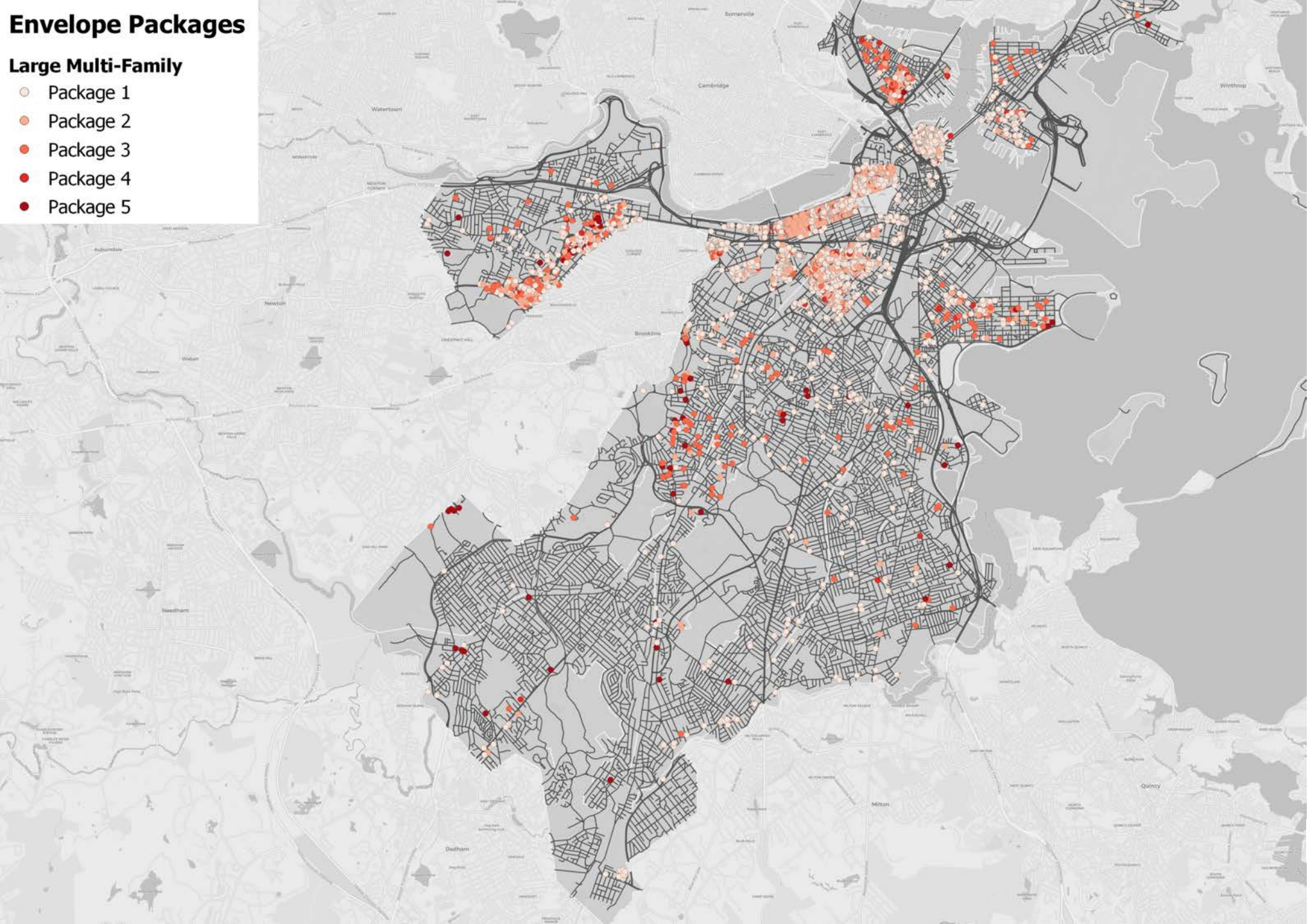
- Small multifamily buildings have more retrofit packages identified, which is due to the greater availability of data.
- Buildings with few or no high-potential envelope retrofits identified likely still have opportunities for envelope energy savings and should be evaluated further on-site.



Key Takeaways

Based on the available data, there appear to be many opportunities for envelope retrofits in small multifamily buildings.

These buildings tend to be concentrated in the outer Boston neighborhoods, which are generally an older building stock.



Key Takeaways

Opportunities for envelope retrofits in large multifamily buildings for which there is data tend to be clustered in Back Bay, the South End, Charlestown, and along the border of Brookline.

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Multifamily Heat Pump Retrofits

Opportunities for heat pump retrofits are identified using building-level data on building age, building height, heating system type, cooling system type, roof type, lot size, and building size.

Air Source Heat Pump Indicators

Retrofit Criteria	Description	Key Data Indicator	% of Small Multifamily (2-3 Units) with Values	% of Large Multifamily (4+ Units) with Values
Electrical Capacity	Assumptions on if there is sufficient electrical capacity (at least ~200 amps) in the building, or if the building would require an electrical panel upgrade.	A/C Type	100%	37%
		Year Built	100%	98%
Distribution	Assumptions on the heating and/or cooling distribution such as ducts or pipes to match to expected heat pump technology.	Heating Type	100%	40%
		A/C Type	100%	37%
Line Length/ Location of Outdoor Components	Assumptions on if there is space outdoors, on the wall, or on the roof for outdoor components such as condensers or ground source piping. Also includes assumptions on building heights given heat pump technology line length restrictions.	Building Height	100%	97%
		Roof Type	86%	100%
		GIS land estimates	100%	100%
Building Size	Assumptions on appropriateness of building size for technically feasible and cost-effective retrofits.	Gross Area Size	100%	100%

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Data indicator sources: Tax assessor data, Eversource program data, MLS data, MassCEC data, and building footprint GIS analysis

Multifamily Heat Pump Retrofits

The potential heat pump retrofit measures are organized into the five categories below.

Heat Pump Retrofit Categories*

Heat Pump Category	Retrofits
Ducted Air Source Heat Pump (ASHP)	• Heat Pump Only • Heat Pump + Upgrade to Electrical Capacity • Heat Pump + Identify Outdoor Location
Ductless Air Source Heat Pump (ASHP)	• Heat Pump Only • Heat Pump + Upgrade to Electrical Capacity • Heat Pump + Identify Outdoor Location
Ground Source Heat Pump (GSHP)	• Heat Pump Only**
Variable Refrigerant Flow (VRF)	• Heat Pump Only • Heat Pump + Upgrade to Electrical Capacity
Air to Water Heat Pump (AWHP)	• Heat Pump Only • Heat Pump + Upgrade to Electrical Capacity

Heat Pump Only Retrofits recommend only the heat pump technology

Heat Pump + Upgrade to Electrical Capacity Retrofits recommend that heat pumps are accompanied with upgrades to the electrical panel

Heat Pump + Identify Outdoor Location recommend that a professional will need to identify where to place the outdoor condenser

*See additional details in the Appendix.
**This analysis assumes that buildings that have sufficient land and heating load for a GSHP will likely already have sufficient electrical capacity and space for outdoor condenser.

Multifamily Heat Pump Retrofits | ASHP Retrofit

ASHP retrofits include both ducted and ductless ASHP retrofit opportunities, which were identified based on the following indicators.

Ductless and Ducted ASHP Indicator Assumptions

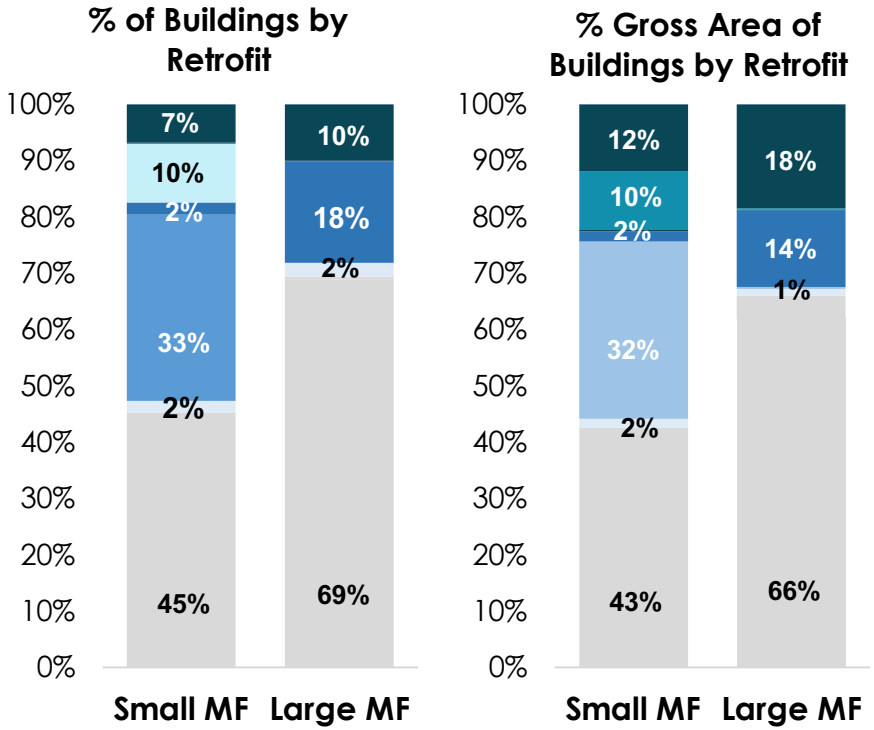
Retrofit Criteria	Ductless ASHP	Ducted ASHP
Distribution System Whether to upgrade to ductless vs. ducted system	• Buildings without forced air and central A/C do not have existing ducts and are therefore better suited for ductless ASHP retrofits.	• Buildings with forced air or central A/C have existing ducts for distribution and therefore may be well-suited for ducted ASHP retrofits, if the ductwork is reusable.
Electrical Capacity Whether there is sufficient electrical panel capacity for a heat pump upgrade	• Larger buildings have a larger baseload and would be more likely to have sufficient electrical capacity for ASHPs. • Newer buildings are more likely to be constructed with sufficient capacity for ASHPS. • Buildings with electrical heating are more likely to have sufficient capacity for ASHPs.	
Line Length/Location of Outdoor Components Whether there is a clear location for the outdoor condenser	• Buildings with existing A/C condensers can reuse the outdoor location for the new ASHP. • Newer roofs may have the structural requirements for roof mounting of the outdoor condenser. • Shorter buildings can site on the ground if there is a 3-foot buffer around the building.	

See additional details on these indicators in the Appendix.

Multifamily Heat Pump Retrofits | ASHP Retrofit

ASHP Retrofit Opportunities

- Ductless ASHPs have wider applicability compared to ducted ASHPs. Smaller multifamily buildings would likely also require upgrades to the electrical panels.
- Nearly 50% of small multifamily buildings do not have a high potential retrofit identified. These likely would require electrical upgrades and would need an outdoor location for condensers.



		# of Buildings		Gross Area of Buildings	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	Ducted ASHP	2,153	690	19,658,491	17,142,394
	Ducted ASHP+Electrical	3,360	1	17,403,853	199,905
	Ducted ASHP+Outdoor	93	17	532,495	148,605
	Ductless ASHP	691	1,244	2,936,900	12,578,576
	Ductless ASHP+Electrical	10,614	2	52,463,621	365,689
	Ductless ASHP+Outdoor	682	170	2,590,330	1,144,165
Unknown Potential	Missing Data	1	4,793	---	57,612,987
	Unknown Retrofit Potential	14,527	31	70,811,599	3,687,906

Multifamily Heat Pump Retrofits | GSHP Retrofit

The potential for GSHP retrofits include are identified based on outdoor space availability, existing heating and cooling system type, and the building size.

GSHP Data Indicator Descriptions

Data Indicator Rules	Heat Pump Only Retrofit	Description
Distribution	Heating: Hot Water and Cooling: Central A/C ***OR*** Heating: Forced Air and Cooling: Central A/C	These can be more easily converted to GSHPs without major modifications.
Line Length/ Location of Outdoor Components	Sufficient available land for boreholes to support the building's heating/cooling load ***AND*** Must be at least 15 ft minimum from foundation and at least 10 ft from adjacent property line	The calculation is based on availability of 20x20 blocks of land for boreholes to meet the heating capacity (based on size) of the building.
Building Size	Gross Area >3,200 feet	Larger buildings may be more cost-effective and feasible compared to smaller buildings.

Data indicator sources: Tax assessor data, Eversource program data, MLS data, MassCEC data, and building footprint GIS analysis.

95 multifamily buildings were identified with high GSHP potential, which account for 2% of multifamily square footage.

		# of Buildings		Gross Area of Buildings	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	GSHP	58	37	697,021	1,959,900
Unknown Potential	Missing Heat Type	1	4,793		57,612,987
	Unknown Retrofit Potential	32,062	2,118	165.7M	22,207,340

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Notes: GSHPs require outdoor space on the building property for boreholes to meet the heating capacity of a building, which limits the applications for many existing buildings. There may be more space available if considering public land, such as alleys, that was not included in this analysis. This retrofit is only appropriate for full replacements of the heating and cooling system, also typically more appropriate for larger buildings for economic and technical reasons.

Multifamily Heat Pump Retrofits | VRF Retrofit

The potential for VRFs retrofits include are identified based on electrical capacity, cooling system type, availability of outdoor space, and building size.

VRF Data Indicator Descriptions

Data Indicator Rules	Heat Pump Only Retrofit	Description
Electrical Capacity	Gross Area >3,000 SF and Central AC ***OR*** Year Built after 1990 ***OR*** Electric Heating	Larger buildings have a larger baseload and then would be likely to have 200 amps. Newer buildings are more likely to have at least 200 amps. Buildings with electrical heating are more likely to have 200 amps.
Distribution	Heating: Not Forced Air ***AND*** A/C: Not Central AC	VRF does not rely on ducted distribution.
Line Length/Location of Outdoor Components	Flat roof and > 1995 Year Built and Height < 30 Stories and 3 foot buffer around building ***OR*** 3 foot buffer around building and Height <15 Stories	Newer roofs may have the structural requirements for roof mounting. Buildings below 15 stories can site on the ground.
Building Size	Gross Area >10,000 SF	Larger buildings may be more cost-effective and feasible compared to smaller buildings

177 multifamily buildings were identified with high VRF potential, which account for 4.7% of multifamily square footage.

		# of Buildings		Gross Area of Buildings	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	VRF	5	171	136,275	4,352,039
	VRF+ Electric		1		114,422
Unknown Potential	Missing Heat Type	1	4,793	---	57,612,987
	Unknown Retrofit Potential	32,115	1,983	166M	30,800,779

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Notes: Variable Refrigerant Flows (VRF), like GSHPs, are only appropriate for full replacements. VRFs also tend to be most applicable for gut renovations when the longer refrigerant lines can be placed in the wall. Similarly, VRFs are typically more appropriate for larger buildings, though the exact building size cutoff is difficult to define.

Data indicator sources: Tax assessor data, Eversource program data, MLS data, MassCEC data, and building footprint GIS analysis.

Multifamily Heat Pump Retrofits | AWHP Retrofit

The potential for AWHP retrofits include are identified based on electrical capacity, heating and cooling system type, and availability of outdoor space.

AWHP Data Indicator Descriptions

Data Indicator Rules	Heat Pump Retrofit	Description
Electrical Capacity	Gross Area >3,000 SF and Central AC ***OR*** Year Built after 1990	Larger buildings have a larger baseload and thus would be likely to have 200 amps. Newer buildings are more likely to have been constructed with at least 200 amps.
Distribution	Heating: Hot Water and Cooling: Central A/C	Existing hydronic distribution for heating and cooling may allow for fewer modifications.
Line Length/Location of Outdoor Components	Central A/C ***OR*** Flat roof and > 1995 Year Built and Height < 30 Stories and 3 foot buffer around building ***OR*** 3 foot buffer around building and Height <15 Stories	Buildings with existing A/C have a location for the outdoor condenser. Newer roofs may have the structural requirements for roof mounting. Shorter buildings can site on the ground.

739 multifamily buildings were identified with high AWHP potential, accounting for roughly 2.5% of multifamily square footage.

		# of Buildings		Gross Area of Buildings	
		Small MF	Large MF	Small MF	Large MF
High Retrofit Potential	AWHP	335	157	2176,493	3,169,501
	AWHP+ Electric	247	---	1119,756	
Unknown Potential	Missing Heat Type	1	4,793		57,612,987
	Unknown Retrofit Potential	31,538	1,998	163.1M	32,097,739

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Note: Analysis assumes that all buildings will need cooling. AWHP retrofit assumes that the baseline building provides heating and cooling, otherwise significant additional investments would be necessary to add cooling to the building. An on-site assessment is also needed to identify if retrofits are needed for the terminal units and distribution system. Data indicator sources: Tax assessor data, Eversource program data, MLS data, MassCEC data, and building footprint GIS analysis..

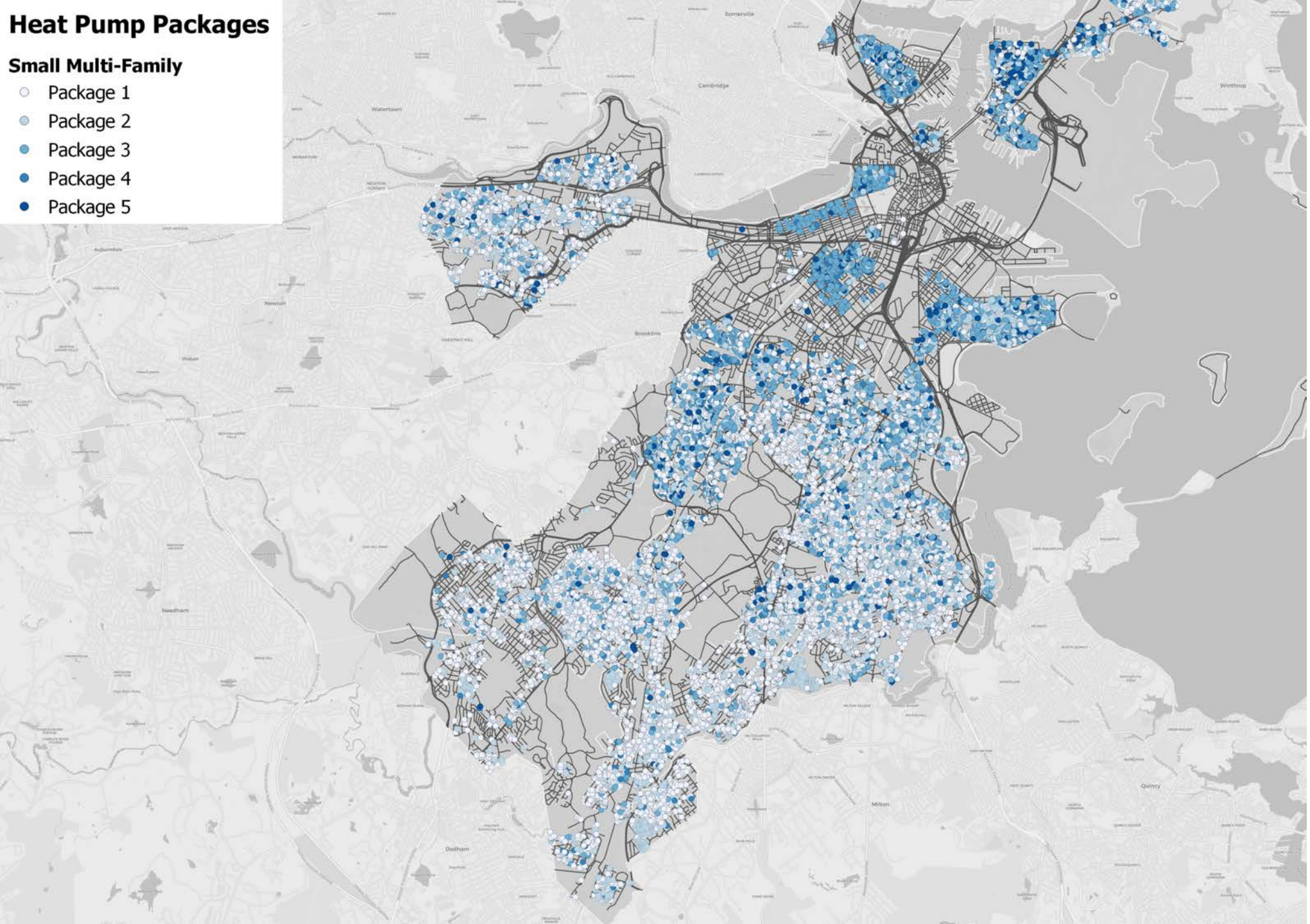
Heat Pump Retrofits | Heat Pump Packages

#	Top 5 Small Multifamily High Potential Heat Pump Retrofit Packages	# of buildings (% of Small MF buildings)	Gross area (% of Small MF Area)
1	Ductless ASHP with Electrical Upgrade	10,614 (33%)	52.5M (32%)
2	Ducted ASHP with Electrical Upgrade	3,113 (10%)	16.3M (10%)
3	Ducted ASHP	1,781 (6%)	17.0M (10%)
4	Ductless ASHP	686 (2%)	2.8M (2%)
5	Ductless ASHP with Outdoor Location	682 (2%)	2.6 (2%)
	Top 5 Small MF High Potential Retrofit Total	**16,874 (53%)**	**91.1M (55%)**

#	Top 5 Large Multifamily High Potential Heat Pump Retrofit Packages	# of buildings (% of Large MF buildings)	Gross area (% of Large MF Area)
1	Ductless ASHP	1,073 (15%)	8.2M (9%)
2	Ducted ASHP	506 (7%)	13.5M (15%)
3	Ductless ASHP or VRF	171 (2%)	4.4M (5%)
4	Ductless ASHP with Outdoor Location	170 (2%)	1.1M (1%)
5	Ducted ASHP or AWHP	147 (2%)	1.6M (2%)
	Top 5 Large MF High Potential Retrofit Total	**2,067 (30%)**	**28.9M (31%)**

The top 5 heat pump retrofit packages account for over 50% of small multifamily buildings and 30% of large multifamily buildings.

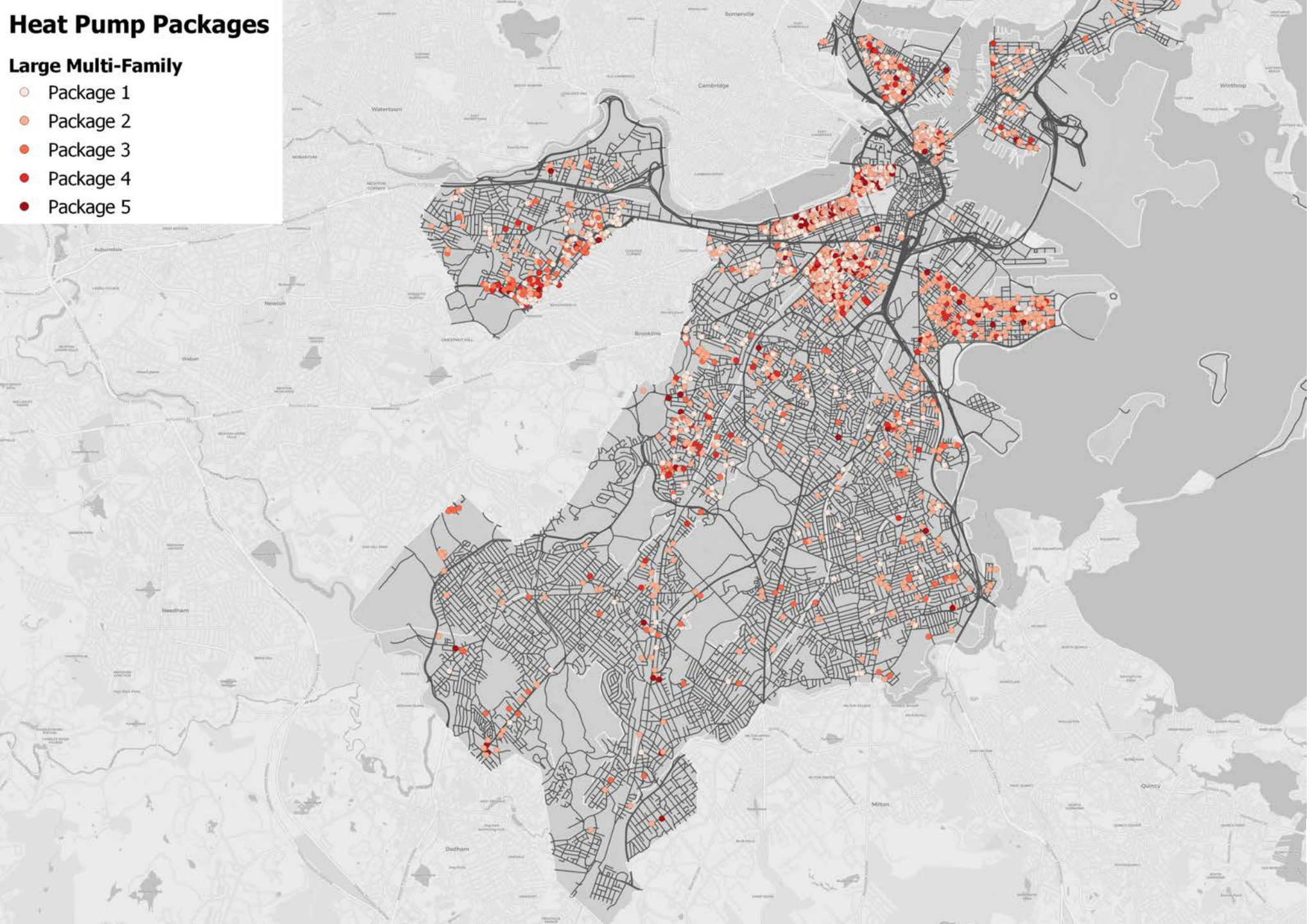
- Both small and large multifamily buildings have more retrofit opportunities with ductless heat pumps than ducted heat pumps.
- Small multifamily buildings are significantly more likely than large multifamily buildings to require an electrical panel upgrade.
- Roughly 40% of large multifamily buildings were missing heating system information, which limited identifying potential heat pump retrofits.



Key Takeaways

Based on available data, heat pump retrofit opportunities for small multifamily buildings appear to be dispersed throughout Boston (more so than potential envelope retrofits).

Additionally, small buildings in Back Bay and the South End appear less likely to need electrical upgrades for heat pumps.



Key Takeaway

Based on available data, there are clusters of large multifamily buildings that could be prioritized for heat pump retrofits in Back Bay, the South End, South Boston, Charlestown, and along the border of Brookline.

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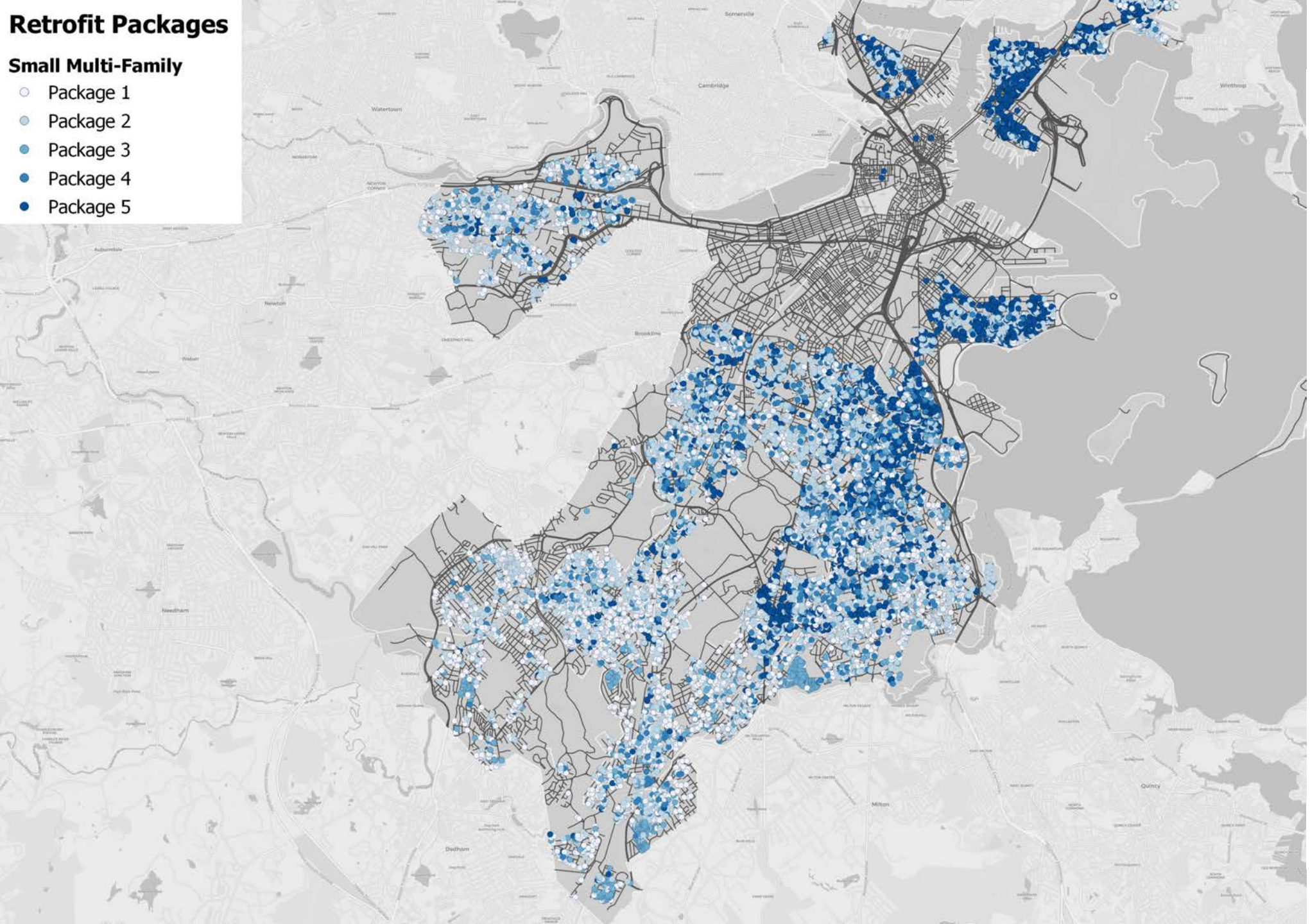
Retrofit Packages | Small Multifamily

Retrofit packages for small multifamily buildings combine both envelope and heat pump retrofits to identify combinations of measures with a high opportunity for potential implementation in Boston.

- The top 5 retrofit packages for small multifamily buildings represent over 50% of small multifamily buildings.
- Retrofits that include an ASHP often require an upgrade to the electrical panel.

#	Top 5 Small Multifamily High Potential Retrofit Packages	# of buildings (% of Small MF buildings)	Gross area (% of Small MF Area)
1	Insulate attic; Insulate exposed pipes; Add blown/spray insulation to interior walls; Ductless ASHP with Electrical Upgrade	6,670 (21%)	31.3M (19%)
2	Insulate attic; Insulate exposed pipes; Add blown/spray insulation to interior walls	5,192 (16%)	24.4 (15%)
3	Add exterior roof insulation; Add blown/spray insulation to interior walls; Insulate pipes	3,631 (11%)	17.4 (10%)
4	Insulate attic; Insulate exposed ducts; Add blown/spray insulation to interior walls; Ducted ASHP with Electrical Upgrade	1,734 (5%)	7.6 (5%)
5	Insulate attic; Insulate exposed ducts; Add blown/spray insulation to interior walls	1,335 (4%)	6.3 (4%)
	Top 5 Small MF High Potential Retrofit Total	**18,562 (58%)**	**87.0M (52%)**

Note for Packages 1 and 2: Exposed pipes should only be insulated if heat pumps are phased in over time.



Key Takeaways

There are clusters of certain types of potential retrofit packages for small multifamily buildings, based on available data.

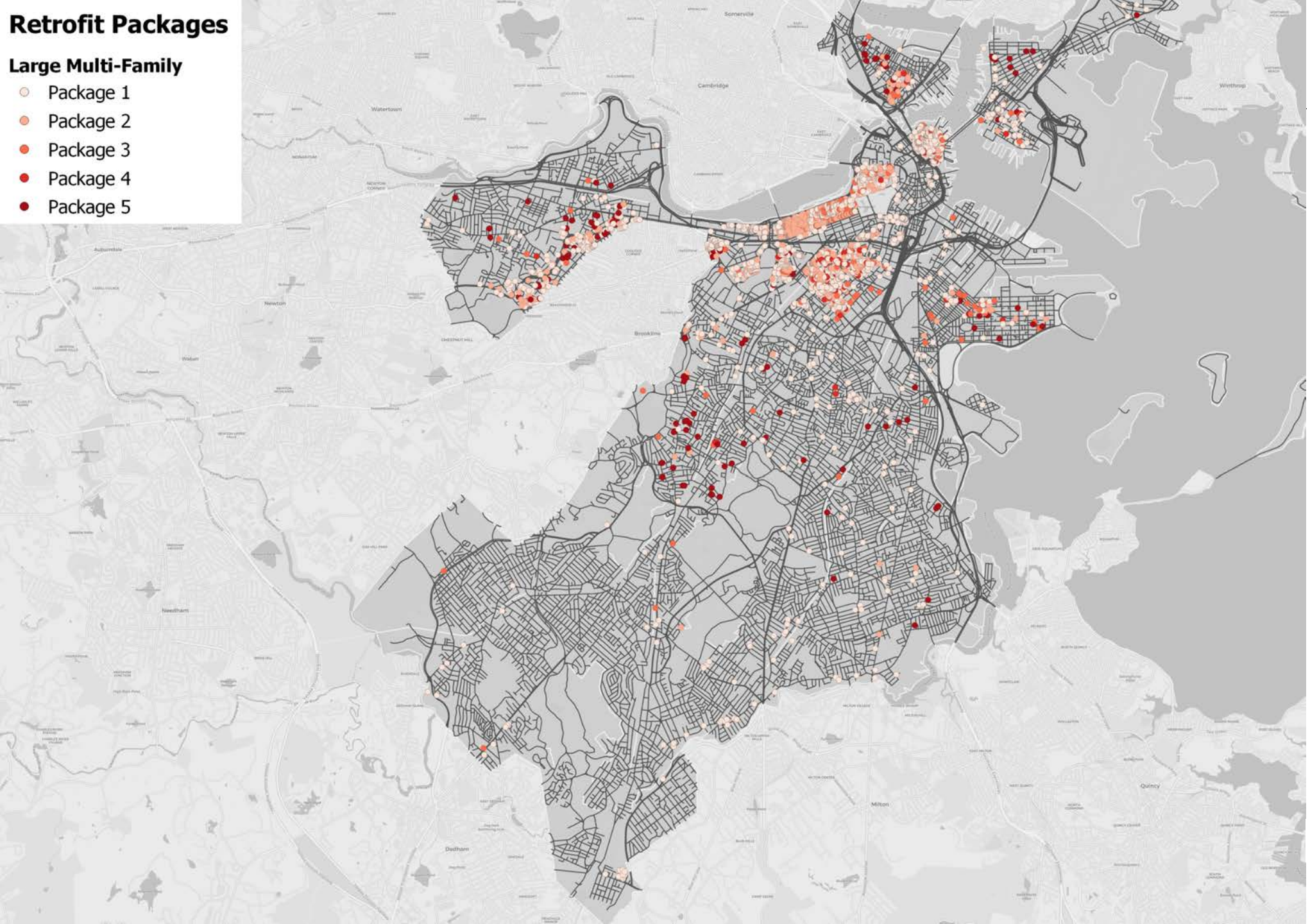
- Ducted buildings, with opportunities for ducted ASHPs and duct insulation, tend to be in South Boston, Roxbury, Dorchester and East Boston.
- Piped buildings, with opportunities for ductless heat pumps and pipe insulation, are in the outer areas including Roslindale, Hyde Park, and Allston/Brighton.

Retrofit Packages | Large Multifamily

Retrofit packages for large multifamily buildings combine both envelope and heat pump retrofits to identify combinations of measures with a high opportunity for potential implementation in Boston.

- The top 5 retrofit packages for large multifamily buildings represent nearly 50% of large multifamily buildings.
- Large multifamily buildings were more likely than smaller buildings to be missing data, making it more difficult to identify potential upgrades, but they may still greatly benefit from envelope and electrification retrofits.

#	Top 5 Large Multifamily High Potential Retrofit Packages	# of buildings (% of Large MF buildings)	Gross area (% of Large MF Area)
1	Add exterior roof insulation	2,102 (30%)	27.8M (30%)
2	Add exterior roof insulation; Insulate exposed pipes; Ductless ASHP	686 (10%)	5.6M (6%)
3	Add exterior roof insulation; Ducted ASHP	185 (3%)	3.3M (4%)
4	Add exterior roof insulation; Ductless ASHP	170 (2%)	1.1M (1%)
5	Add exterior roof insulation; Insulate exposed pipes	143 (2%)	1.0M (1%)
	Top 5 Large MF High Potential Retrofit Total	**3,286 (47%)**	**38.8M (42%)**



Key Takeaways

There are clusters of certain potential retrofit packages for large multifamily buildings, where data is available.

- Larger buildings are clustered in the South End and Back Bay, and they tend to have potential for Retrofit Packages 1 and 2.
- Outer areas of the city have fewer larger buildings, leading to fewer clusters of opportunities in these areas.

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Ownership, Decision-making, & Social Vulnerability Indicators

Ownership, decision-making, and social vulnerability indicators can help predict non-technical opportunities or barriers to retrofits.

- These indicators provide insights on how building owners make decisions, who those decisions impact, and any potential associated risks or impacts to the tenants.
- Combined with technical retrofit packages, these indicators are particularly critical for policy and program development because they can help policymakers identify and prioritize buildings with the highest need for assistance.

Ownership, Decision-making, and Social Vulnerability Categories

Indicator Category	Description
Ownership Indicators	These indicators may predict decision-making styles to inform intervention strategies and support.
Decision-making Indicators	These indicators may predict a higher likelihood of early adopters of new technologies to shape outreach and messaging strategies.
Social Vulnerability Indicators	These indicators may predict higher likelihood of being negatively impacted by increased rents or energy costs, and positively impacted by health and building quality benefits from retrofits.

Ownership Indicators

Ownership indicators can help identify opportunities and challenges that different types of owners will face when it comes to implementing retrofits.

Ownership Indicator Prevalence in Multifamily Buildings

Type	Assumption	% of Large MF	% of Small MF
Owner-occupied	Owner occupied building may indicate a higher likelihood of investing in retrofits for non-economic drivers. Percentages do not include buildings with common ownership.	7%	51%
Regulated affordable housing	Owners of affordable housing have limits on rent increase from retrofit costs and may have greater interactions with the city through financing programs.	6%	1%
Cooperative building	These buildings have more challenging decision-making and will need strategic and prolonged support for working with their boards.	30%	3%
Buildings privately owned	Privately owned buildings often have limited options for interventions- either encouraging voluntary actions or mandating changes. These may risk passing retrofit costs onto tenants.	64%	97%
Buildings publicly owned	Publicly owned buildings may offer retrofit opportunities by developing relationships and provided targeted support to city departments.	1%	0%
Historic/ Landmark	Buildings classified as historic or within a landscape district will need additional support and may be less willing/interested in retrofits	47%	6%

Note: Buildings not included in these percentages do not meet the category criteria or are missing data for this category.

Data indicator sources: Tax assessor data, income-restricted housing data, and Historic & Landmark District GIS data.

Decision-Making Indicators (Early Adopters)

Decision-making indicators can help identify owners or decision-makers who are more likely to voluntarily retrofit their buildings, given certain characteristics or history of making similar upgrades.

Decision-making Indicator Prevalence in Multifamily Buildings

Type	Assumption	% of Large MF	% of Small MF
Owner Occupied	Owner occupied building may indicate a higher likelihood of investing in retrofits for non-economic drivers. Percentages do not include buildings with common ownership.	7%	51%
Buildings with PV	These buildings have better economics for heat pumps and may indicate owners that are more inclined to install heat pumps as they are new technologies.	1%	3%
Buildings with lower rates of tenants with children*	Mass Save identified that families with children were least likely to participate in their programs due to time and money priorities.	44%	9%
Buildings with higher rates of tenants with higher income*	Households with higher rates of income may be more able to bear the higher costs of heat pump installations that is typically associated with early adopters.	41%	14%
Buildings with higher rates of seniors*	Mass Save identified that households with seniors are most likely to participate in their programs as they view these as good investments in their long-term home ownership.	23%	21%

*Assumes top quartile of census tracts.

Data indicator sources: Tax assessor data, US Census ACS data, Climate Ready Boston Social Vulnerability indicators & permit data.

Social Vulnerability Indicators

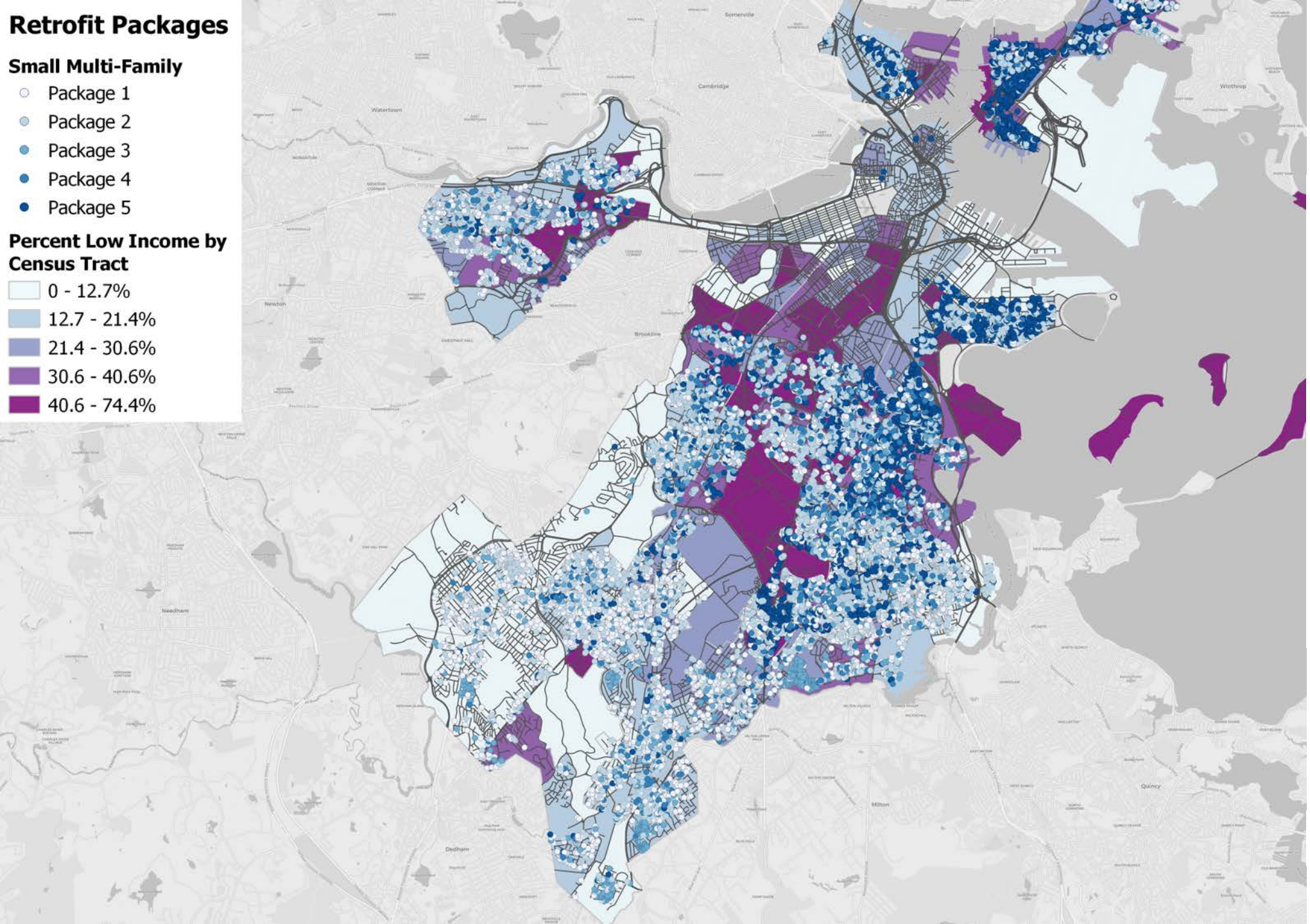
Social vulnerability indicators help identify specific buildings or buildings in certain areas that have socioeconomic vulnerabilities that may justify prioritization for financial or technical assistance.

Social Vulnerability Indicator Prevalence in Multifamily Buildings

Type	Assumption	% of Large MF	% of Small MF
Regulated affordable housing	Regulated affordable housing tend to house the city's low-income population, though tend to have restrictions to limit rent and operating cost increases.	6%	1%
Census tracts with higher rates of tenants with disabilities*	May need interventions to assist in living in-place. Heat pumps can offer cooling to the populations more at risk of heat-related illnesses.	12%	28%
Census tracts with higher rates of tenants with children*	Children may be more at risk of asthma in households with gas cooking and therefore may have greater need to convert these to all-electric buildings.	11%	32%
Census tracts with higher rates of tenants who are people of color*	In Boston, people of color statistically have lower levels of income and higher levels of poverty, which puts them at greater risk of climate impacts such as extreme heat and flooding and affordability from rent and energy cost increases.	13%	33%
Census tracts with higher rates of tenants with limited English proficiency*	These areas may have a higher need of multi-cultural, multi-lingual outreach, education, and assistance from culturally-competent staff.	17%	17%
Census tracts with higher rates of tenants with low to no income*	These tenants are more at risk of climate impacts, energy cost burdens, and poor living conditions. They would likely greatly benefit from envelope and heat pump retrofits, though cannot support increased energy costs.	17%	18%

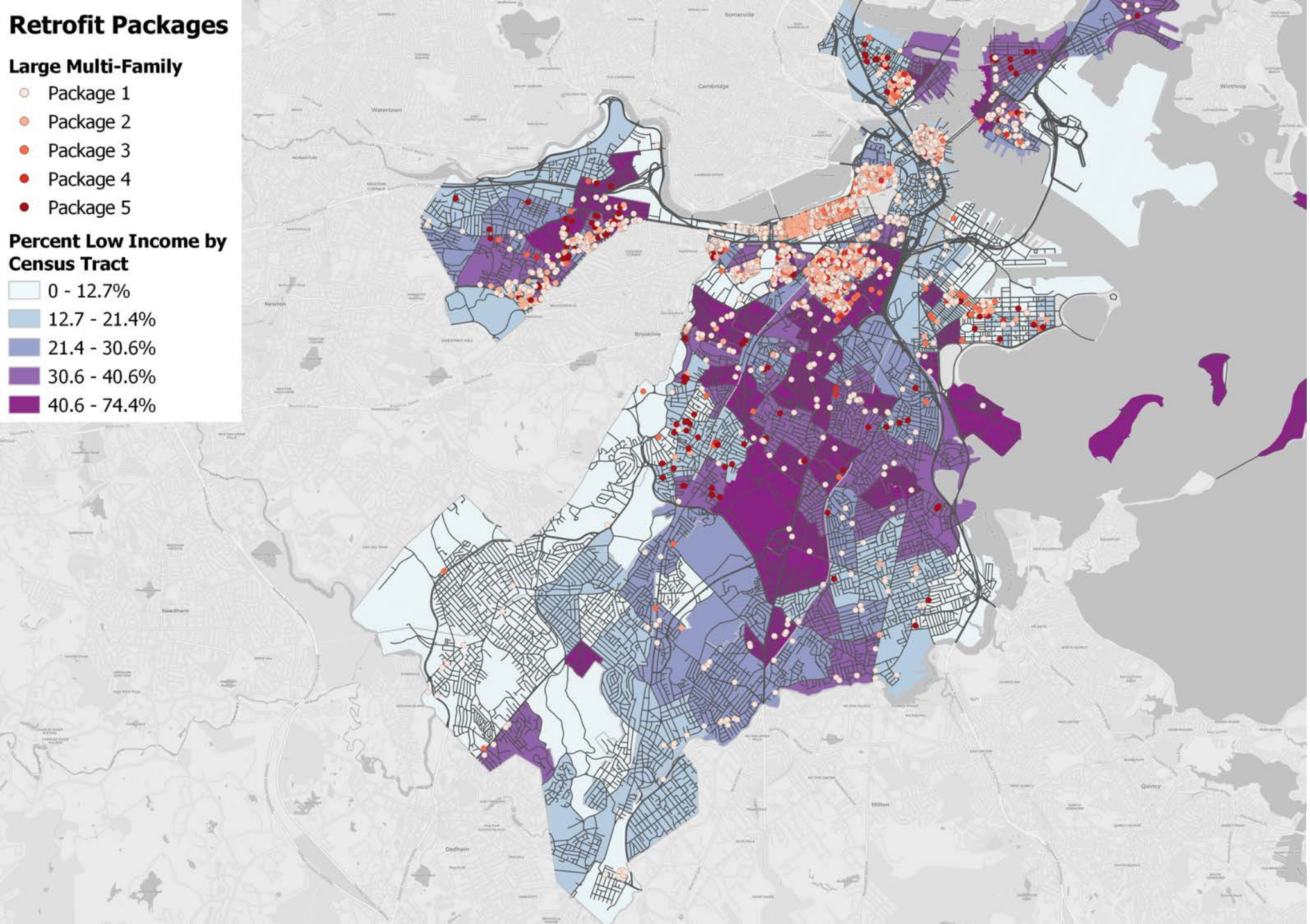
*Assumes top quartile of census tracts.

Data indicator sources: Tax assessor data, income-restricted housing data & Climate Ready Boston Social Vulnerability indicators.



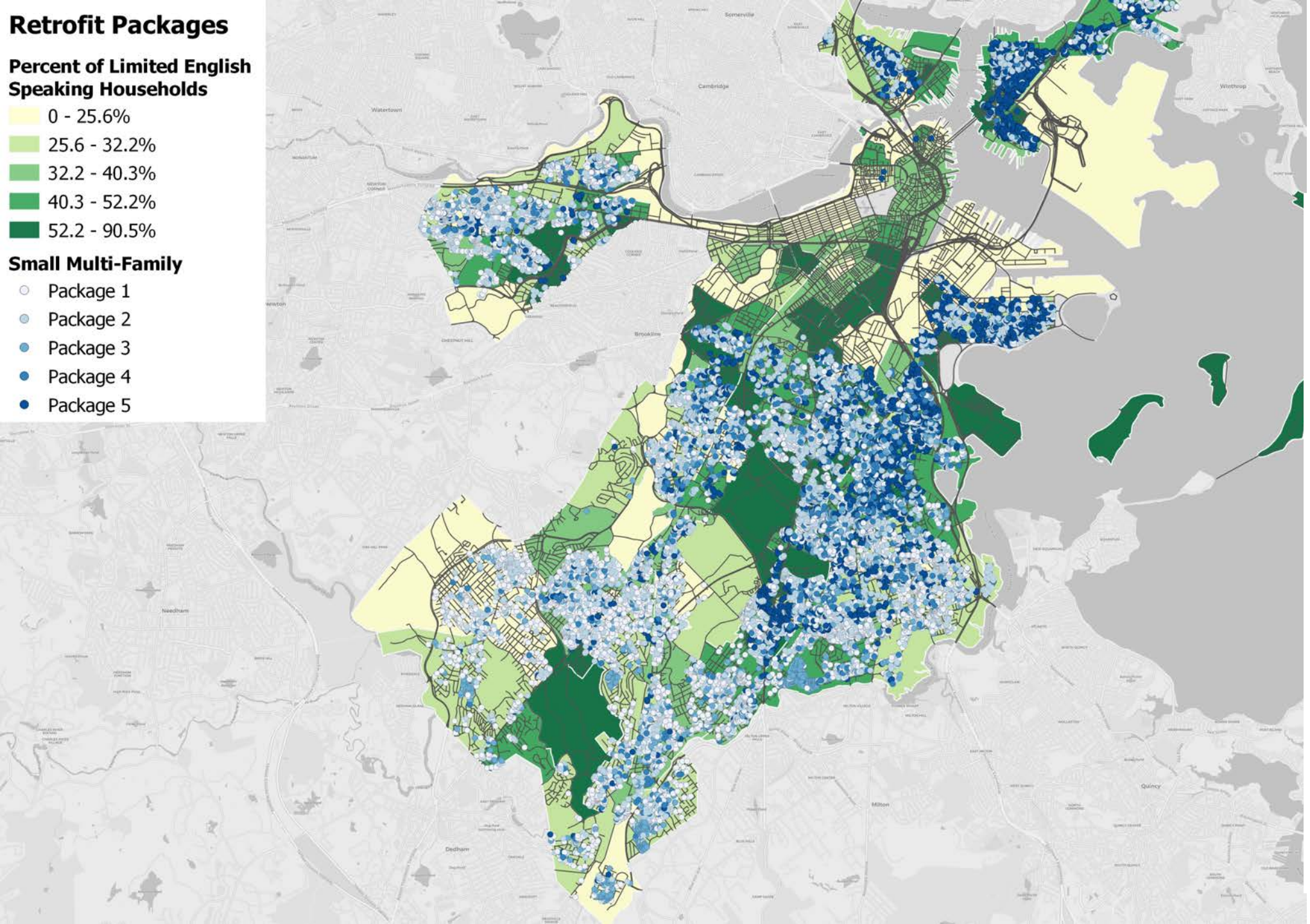
Low Income Census Tracts and Small Multifamily Building Retrofit Opportunities

Small multifamily buildings with high retrofit potential are clustered in several lower-income census tracts, including East Boston, Allston/ Brighton, Roxbury, Dorchester, and Jamaica Plain.



Low Income Census Tracts and Large Multifamily Building Retrofit Opportunities

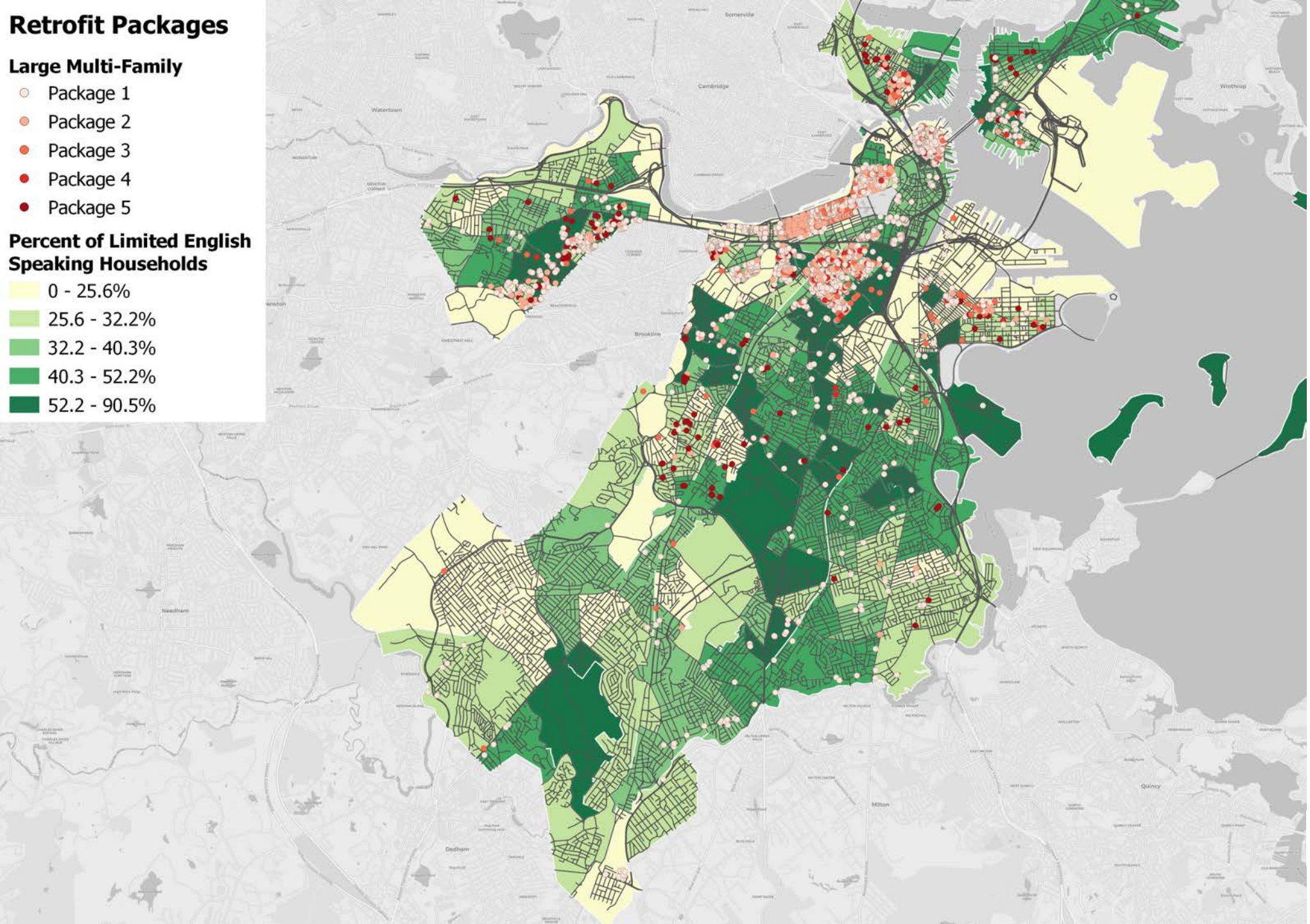
Large multifamily buildings are less clustered than small multifamily buildings in census tracts with low-income households, and instead tend to be in higher-income areas like Back Bay, Beacon Hill, Central Boston, and the South End.



Limited English Proficiency and Small Multifamily Building Retrofit Opportunities

Census tracts with limited English-speaking household largely overlap with low-income census tracts.

There are many small multifamily buildings with high retrofit potential clustered in these areas. Outreach to buildings in these areas should include resources in the appropriate languages.



Limited English Proficiency and Large Multifamily Building Retrofit Opportunities

There are some clusters of large multifamily buildings in areas with limited English-speaking households, including Chinatown, the South End, and parts of Allston/ Brighton along the Brookline border.

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Recommendations

Building on this multifamily housing stock analysis, BEI offers the following recommendations to help Boston design a program that will scale up energy efficiency and electrification retrofits in multifamily buildings:

- **Identify high-priority building sectors and design program support around their retrofit opportunities and needs.** This analysis can be shared with stakeholders and community groups to identify and prioritize buildings in the greatest need of upgrades and their specific retrofit opportunities. Stakeholders can also provide valuable insights on strategies for engagement and and program support for these buildings.
- **Prioritize buildings for program support based on their social vulnerabilities and other equity considerations.** Multifamily buildings that house low-income residents and other Bostonians with social vulnerabilities will likely need the greatest levels of support to implement efficiency and electrification retrofit projects, and their residents also stand to benefit most from the health, safety, and comfort benefits of the upgrades.
- **Provide specific retrofit recommendations to building decision-makers and offer assistance that is tailored to their ownership, decision-making, and social vulnerability factors.** Based on past program experience, the more specific project opportunities that can be recommended, the more quickly and likely a building decision-maker will decide to act. Funding opportunities and other types of assistance available should also be tailored based on ownership, decision-making, and socioeconomic factors.
- **As new programs are implemented, document findings that result from the experience of directly engaging with building decision-makers.** This analysis represents information that could be gleaned from data analysis as a starting point for engaging with buildings. Even more important takeaways will emerge from directly engaging with building owners and decision-makers, which can further inform future programs, policies, and strategies.

Appendix

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Envelope Retrofits | Additional Details

Specific Measures included in the Standard Envelope Retrofit

Retrofit	Description
Air Sealing and Weather Stripping	Air sealing/Caulking/Weather-stripping around windows and doors and other openings
Window Upgrades at the Time of Replacement	Upgrade windows at the time of replacement to at least a U-factor of ~0.30 or triple glazed, low-e windows
Insulate Rim Joist	Insulate rim joists to insulation levels between R-17 to R-40 levels

Specific Measures and Indicators Used to Identity the Attic/Roof Retrofit

Retrofit	Roof Type Data Indicator	Additional Data Indicator	Description
Insulate Attic	Gable, Hip, Gambrel, Mansard	Major Rehab and Year Built before 1995	Add blown-in insulation from interior to the maximum amount possible
Interior Insulation in Converted Attic	Gable, Hip, Gambrel, Mansard	Major Rehab or Year Built after 1995	Add blown-in insulation from interior to the maximum amount possible. Less insulation is possible in converted attics.
Exterior Roof Insulation	Flat	Year Built before 2008	Add insulation to the top of the roof (typically at the time of roof replacement) and, if there is a cavity, add blown in insulation from outside the building into the cavity.

Envelope Retrofits | Additional Details

Specific Measures and Indicators Used to Identity in the Wall Retrofit

Retrofit	Exterior Finish Data Indicator	Additional Data Indicators	Description
Interior Blown/Spray Insulation	Wood Shake, Brick/Stone Veneer, Aluminum, Frame/Clapboard, Vinyl	Year Built <1980 ***OR*** <50 Units OR >3 stories OR Historical District/Landmark Building	Add Blown/Spray insulation to the max amount possible from within units.
Interior Wall Insulation Board	Stucco, Asphalt, Concrete, Brick/Stone		Add an insulation board between interior finish and mass wall, preferably at the time of replacement of interior wall.
Insulate Behind Spandrel	Glass		Add insulation behind spandrel to the maximum amount possible.
Exterior Wall Insulation at Time of Replacement	Wood Shake, Brick/Stone Veneer, Aluminum, Frame/Clapboard, Vinyl	>50 Units and Height <3 stories ***OR*** NOT Historical District/Landmark Building ***OR*** 3 foot buffer around property	Reclad and add exterior insulation when exterior is being replaced. Add blown insulation from exterior to cavity before interior wall if possible.
Exterior Wall Insulation	Stucco, Asphalt, Concrete, Brick/Stone		Reclad and add exterior insulation. This retrofit will likely have diminishing returns for larger buildings and should be evaluated by professionals.
Consult Professional	Asbestos siding		Consult a professional on the preferred method for adding insulation to the envelope, given the location and quantity of the asbestos.

Notes: Adding insulation to interior walls is likely preferable when there are fewer units to enter or the building is taller, which would require additional equipment to reclad. In larger and shorter buildings, exterior recladding and insulation may be preferable. While non-mass wall exteriors are replaced periodically and the retrofit can be timed with replacement, mass wall exteriors are rarely replaced. Recladding these may be possible, although this can be costly and may have diminishing returns. Data is not available on which buildings have already completed the wall retrofits listed above.

Heat Pump Retrofits | Additional Details

Indicators Used to Identify Ducted ASHP Retrofits

Data Indicator Rules	Heat Pump Only Retrofit	+ Electric Upgrade Retrofit	+ Outdoor Location Retrofit	Description
Electrical Capacity	Gross Area >3,000 SF and Central AC ***OR*** Year Built after 1990		Gross Area >3,000 SF and Central AC ***OR*** Year Built after 1990	Larger buildings have a larger baseload and then would be likely to have 200 amps. Newer buildings are more likely to have been constructed with at least 200 amps.
Distribution	Heating: Forced Air ***OR*** A/C: Central AC			Buildings with forced air or central A/C have existing ducts for distribution.
Line Length /Location of Outdoor Components	Central A/C and Height <9 Stories ***OR*** Flat roof and > 1995 Year Built and Height < 9 Stories ***OR*** 3 foot buffer around building + <5 Stories		No 3 foot buffer around building + <5 Stories	Buildings with existing A/C have a current location for the outdoor condenser. Newer roofs may have the structural requirements for roof mounting. Shorter buildings can site on the ground if there is a 3 foot buffer around the building.

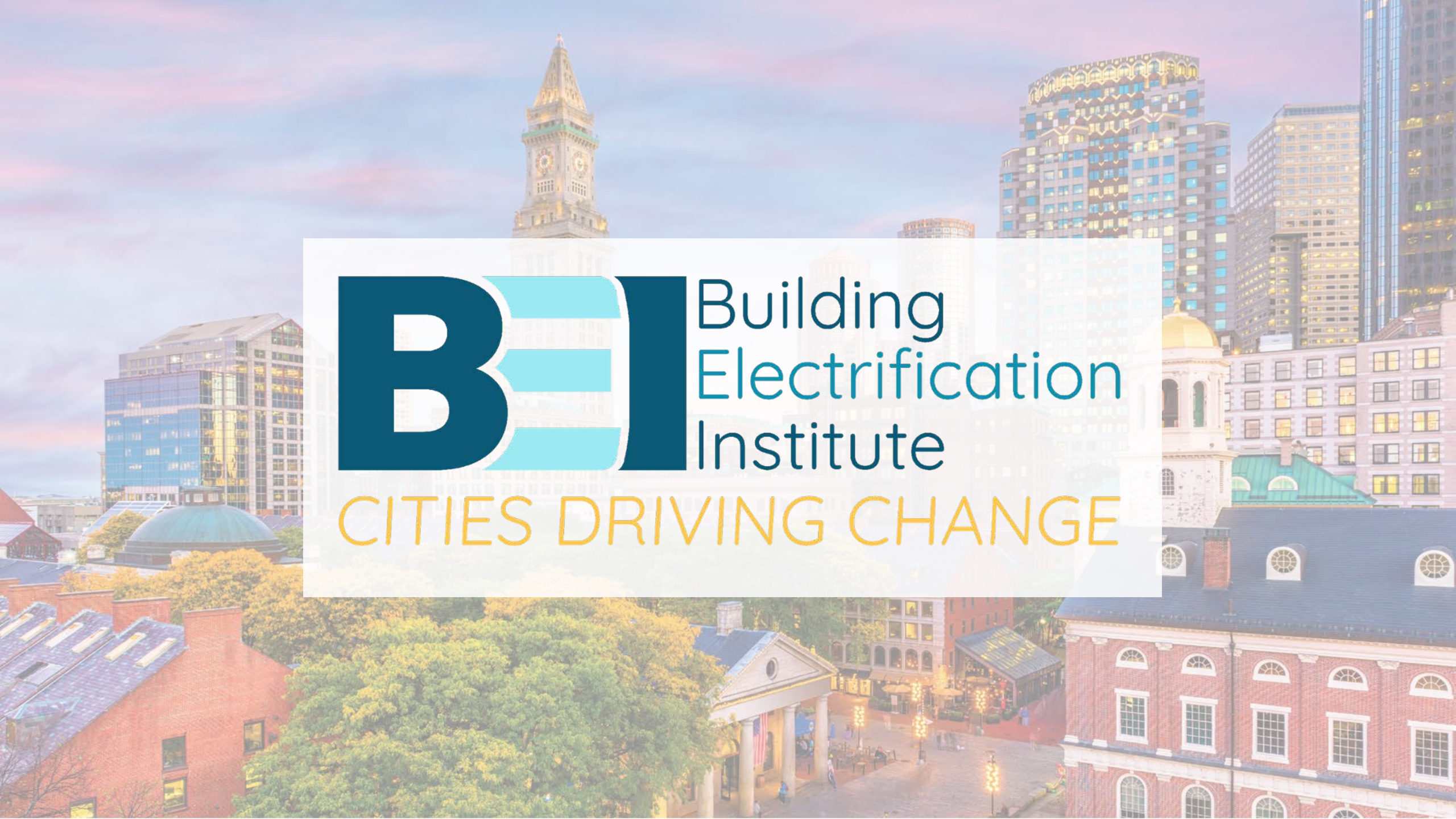
Notes: Ducted ASHPs are most appropriate in buildings that currently have ducts from heating or a central A/C system. An on-site assessment is important to evaluate the capacity of heat pump needed, location of outdoor condenser, and if the existing ducts are sized and located appropriately for a ducted heat pump. Boston buildings should install cold-climate heat pumps given the climate. Ducted heat pumps can be a displacement or replacement strategy, with appropriate controls.

Heat Pump Retrofits | Additional Details

Indicators Used to Identify Ductless ASHP Retrofits

Data Indicator Rules	Heat Pump Only Retrofit	+ Electric Upgrade Retrofit	+ Outdoor Location Retrofit	Description
Electrical Capacity	Gross Area >3,000 SF and Central AC ***OR*** Year Built after 1990 ***OR*** Electric Heating		Gross Area >3,000 SF and Central AC ***OR*** Year Built after 1990 ***OR*** Electric Heating	Larger buildings have a larger baseload and thus would be likely to have 200 amps. Newer buildings are more likely to have been constructed with at least 200 amps. Buildings with electrical heating are more likely to have 200 amps.
Distribution	Heating: NOT Forced Air ***AND*** A/C: NOT Central AC			Buildings without forced air and central A/C do not have existing ducts.
Line Length/Location of Outdoor Components	Exterior: brick/stucco/concrete and NOT Landmark/Historical District ***OR*** Flat roof and > 1995 Year Built and Height < 9 Stories ***OR*** 3 foot buffer around building + <5 Stories		No 3 foot buffer around building + <5 Stories	Buildings with existing A/C have a current location for the outdoor condenser. Newer roofs may have the structural requirements for roof mounting. Shorter buildings can site on the ground.

Notes: Ductless ASHPs are most appropriate in buildings that do not have ducts from heating or a central A/C system. An on-site assessment is important to identify the locations of the indoor and outdoor units to provide sufficient heating. Boston buildings should install cold-climate heat pumps given the climate. Ductless heat pumps can be displacement or replacement strategies, depending on the existing heating system and configuration.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