A BETTER CITY

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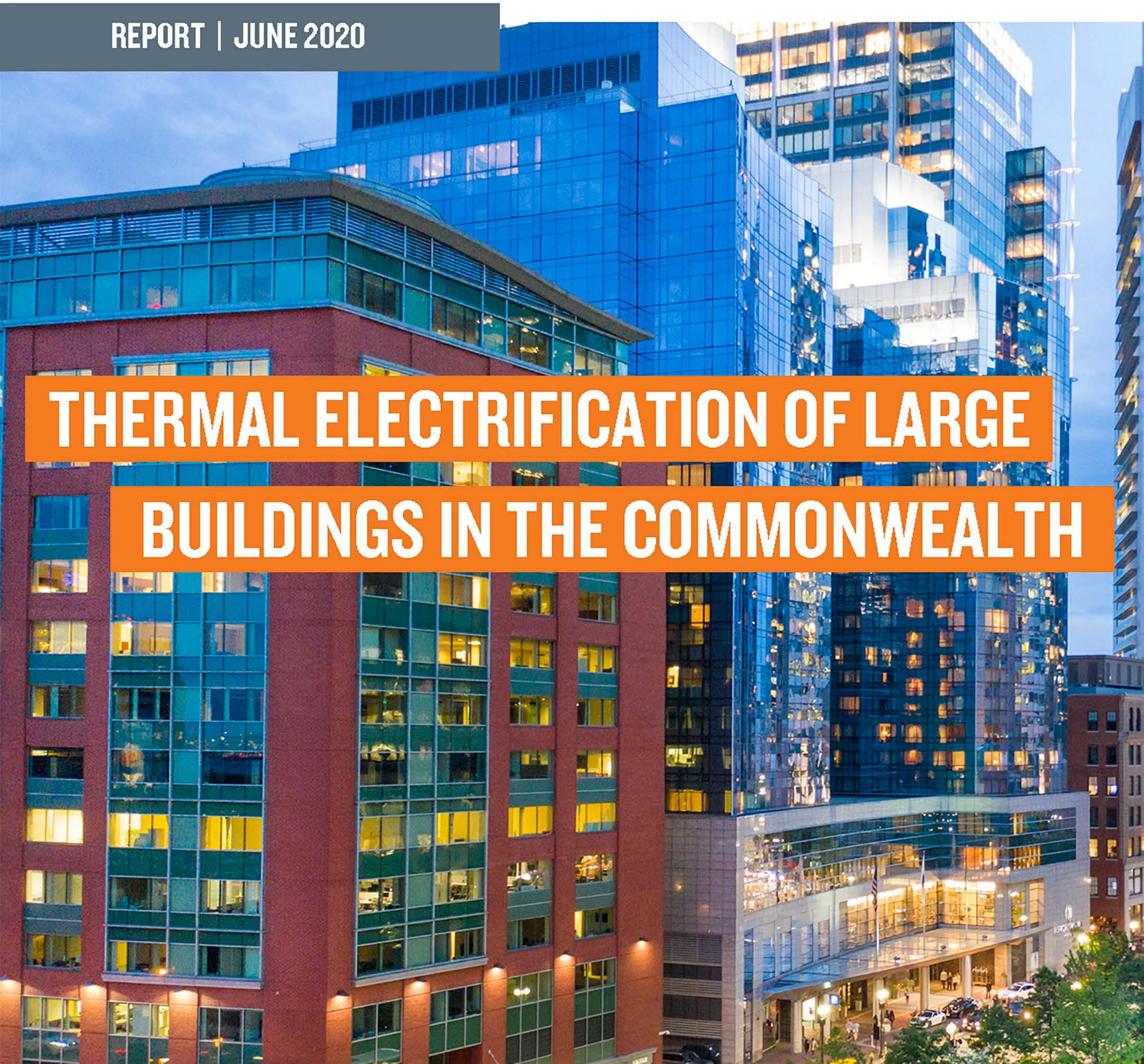

THERMAL ELECTRIFICATION OF LARGE BUILDINGS IN THE COMMONWEALTH

ACKNOWLEDGMENTS

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A Better City is a diverse group of business leaders united around a common goal—to enhance Boston and the region's economic health, competitiveness, vibrancy, sustainability and quality of life. By amplifying the voice of the business community through collaboration and consensus across a broad range of stakeholders, A Better City develops solutions and influences policy in three critical areas central to the Boston region's economic competitiveness and growth: transportation and infrastructure, land use and development, and energy and environment.

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EXECUTIVE SUMMARY

INTRODUCTION

Reducing carbon emissions from large buildings is key to the City of Boston and Commonwealth of Massachusetts meeting their respective carbon neutrality goals by 2050, as commercial, industrial, and large residential buildings accounted for 51.6 percent of greenhouse gas emissions in the City of Boston in 2017,[i] and commercial buildings accounted for 10.1 percent in the Commonwealth in the same year.[ii] There are four primary strategies for large building decarbonization: zero net carbon standards; energy efficiency; renewable energy; and the transition of space heating and cooling, and hot water to non-fossil fuels, primarily through electrification powered by renewable energy.

There are currently workable solutions for three of these four core strategies. A recent report indicates that zero energy buildings are being built across Massachusetts today with minimal or no additional upfront costs[iii] Comprehensive upgrades to commercial buildings can reduce their energy use by 20-50%.[iv] There are also price-competitive options for building owners to install on-site renewable energy or purchase renewable energy through Power Purchase Agreements (PPAs), directly or "virtually".

For the fourth core strategy—the transition of space heating and cooling and hot water to non-fossil fuels, primarily through electrification—there are far fewer case studies and the path forward is less clear. This report, therefore, is intended to provide an overview, thus far, of thermal electrification strategies for large commercial and multifamily buildings in Boston and Massachusetts, reviewing current feasible technologies and their costs, emerging technologies, barriers to deployment, policy options and strategies for overcoming barriers, and case studies.

TECHNOLOGIES

The market-ready thermal electrification technologies with significant uptake in the Boston area currently are air-source heat pumps, variable refrigerant flow heat pumps, and ground-source heat pumps:

IMAGE 1

AIR-SOURCE HEAT PUMPS (ASHPS) are an electric HVAC appliance that transfers heat between outdoor air and conditioned indoor space to provide heating and cooling, providing individual unit comfort control with independent systems.

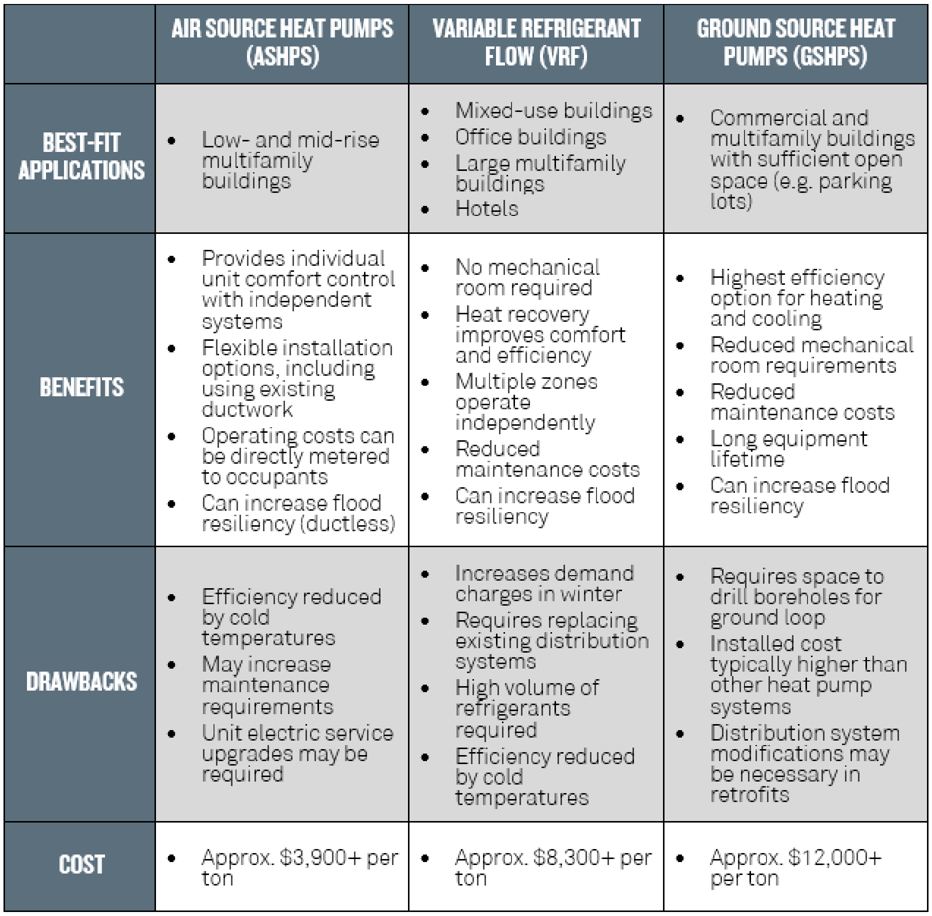
IMAGE 2

VARIABLE REFRIGERANT FLOW (VRFS) heat pumps are centralized systems with greater heating and cooling capacity than residential and light commercial ASHPs and are often installed with a heat recovery feature that allows for simultaneous heating and cooling within zones to improve comfort and efficiency.

IMAGE 3

GROUND-SOURCE HEAT PUMPS (GSHPS) use a heat pump coupled to a fluid loop buried underground that transfers heat between the ground and the building. The system can provide space heating and cooling by circulating hot or chilled water through a hydronic system or by using forced-air ductwork.

Applications, benefits, drawbacks, and costs are summarized in the table below, though costs vary widely depending on outdoor and indoor conditions. *(All cost estimates are based on median installed costs from projects rebated through the Massachusetts Clean Energy Center's (MassCEC) Clean Heating and Cooling Program).*



	AIR SOURCE HEAT PUMPS (ASHPS)	VARIABLE REFRIGERANT FLOW (VRF)	GROUND SOURCE HEAT PUMPS (GSHPS)
BEST-FIT APPLICATIONS	• Low- and mid-rise multifamily buildings	• Mixed-use buildings • Office buildings • Large multifamily buildings • Hotels	• Commercial and multifamily buildings with sufficient open space (e.g. parking lots)
BENEFITS	• Provides individual unit comfort control with independent systems • Flexible installation options, including using existing ductwork • Operating costs can be directly metered to occupants • Can increase flood resiliency (ductless)	• No mechanical room required • Heat recovery improves comfort and efficiency • Multiple zones operate independently • Reduced maintenance costs • Can increase flood resiliency	• Highest efficiency option for heating and cooling • Reduced mechanical room requirements • Reduced maintenance costs • Long equipment lifetime • Can increase flood resiliency
DRAWBACKS	• Efficiency reduced by cold temperatures • May increase maintenance requirements • Unit electric service upgrades may be required	• Increases demand charges in winter • Requires replacing existing distribution systems • High volume of refrigerants required • Efficiency reduced by cold temperatures	• Requires space to drill boreholes for ground loop • Installed cost typically higher than other heat pump systems • Distribution system modifications may be necessary in retrofits
COST	• Approx. $3,900+ per ton	• Approx. $8,300+ per ton	• Approx. $12,000+ per ton

EMERGING TECHNOLOGIES

Some emerging technologies are discussed in the report that have the potential to provide or support thermal electrification solutions, but have seen minimal market deployment to-date:

• Hydrogen is considered a potential complementary technology to heat pumps in order to achieve thermal decarbonization, but technology gaps exist and extensive infrastructure for distributing hydrogen has yet to emerge in the Boston area.

• Air-to-water heat pumps (AWHPs) are a heating and cooling technology similar to ASHPs but the primary barriers to installation in the U.S. are technology availability and compatibility with existing hydronic distribution.

• District geothermal has the potential to address many barriers to individual geothermal installations within an urban context, but the financing and business model for larger scale district geothermal networks owned by a third-party has yet to be tested in Massachusetts.

BARRIERS

Several key barriers to deployment of thermal electrification technologies in commercial buildings include:

- **ECONOMICS:** These technologies typically have higher upfront costs than conventional fossil fuel equipment especially in retrofit applications. They can offer cooling operating cost savings, but higher heating costs due to the current low cost of fossil fuels and high cost of electricity, which can make the overall return on investment poor or non-existent in many applications. These cost barriers are reduced in new construction projects, becoming more competitive with conventional alternatives.

- **POLICY & REGULATORY:** Massachusetts' new statewide targets for total energy savings across all fuels allows utilities to account for and incentivize energy savings from switching between heating fuels where cost-effective. However, as switching from gas to electric is not currently cost-effective, utilities are limited in incentivizing thermal electrification. Also, benefits provided by thermal electrification technologies such as greenhouse gas emissions reductions are not always valued in existing markets and regulatory structures.

- **DECISION MAKING:** Some building owners may have goals that disincentivize building electrification like owners that plan to buy a building and sell it relatively quickly, rather than invest in the property long-term. Leasing structures can also lead to split incentives between building owners and building tenants.

- **AWARENESS:** Familiarity and experience with thermal electrification systems is low among building practitioners so building owners are often unaware that thermal electrification is an option to pursue. Also, when an HVAC system breaks down unexpectedly, building managers generally aim for a like-for-like replacement that reduces risk, installation costs, and time that the building is not meeting occupant comfort needs.

- **TECHNICAL & BUILDING:** Thermal technology installation can be a highly disruptive process that requires a major overhaul of building systems, making it most appropriate when combined with other major building renovations. The technologies can also face challenges integrating with -or do not use - existing building heating and cooling distribution systems.

- **WORKFORCE:** HVAC contractors are often unfamiliar with heat pump installation, maintenance, and incentive programs so see them as riskier than conventional systems. Also, maintenance staff will need to re-train from conventional fossil fuel appliance to new thermal electrification technologies.

POLICY OPTIONS & STRATEGIES

A variety of policies and strategies will be required to address the market barriers to thermal electrification technologies including policies that can be implemented by state and local governments—and encouraged by stakeholders in commercial real estate—that adopt practices that reduce financial risk, advocate for measures to improve cost-effectiveness, and advocate for codes, standards and mandates to accelerate thermal electrification.

For commercial real estate stakeholders, promoting standardization efforts related to thermal electrification projects, implementing green leasing strategies, exploring third-party ownership models for renewable thermal installations, and using advanced metering to improve building performance data quality are all strategies that can be pursued.

CASE STUDIES

A set of five case studies illustrates the use of technologies in large buildings across use types, at different stages of development, in both existing buildings and new construction, and in varying states of occupancy. These include:

- A GSHP project in an existing historic municipal building of 14,000 square feet with occupants relocated during construction

- A VRF project in an existing commercial office building of 22,000 square feet with occupants relocated during construction

- A VRF project in an existing commercial office building of 71,000 square feet over four floors with occupants present during construction

- A VRF project in an existing multifamily residential building of 153 units with occupants present during partial construction and individual units converted when tenants allow contractors into their units or upon turnover

- A GSHP project in a newly constructed higher education building of 345,000 square feet over 19 stories

CONCLUSION

Although some zero energy buildings are being built across Massachusetts today with minimal or no additional upfront costs, thermal electrification retrofits in most existing large buildings are not yet cost competitive with natural gas. In some cases, the solutions do pay for themselves over their lifecycle, but the length of the payback and the capital intensity of the investment make them difficult to finance, and other barriers hinder deployment. It is therefore unlikely that thermal electrification will see widespread deployment in the absence of increased incentives and the implementation of mandates that necessitate electrification. A variety of policies and strategies will be required to address the market barriers to thermal electrification technologies. The large buildings sector must play a vital role in working with state and local governments to assess the variety of policy solutions and complementary strategies outlined in this report and develop a thermal electrification pathway forward that can lead to the intended greenhouse-gas emission reductions.

INTRODUCTION

Space heating for large commercial buildings, including multifamily buildings, office buildings, higher education facilities, laboratories, and hotels, is a major contributor to greenhouse gas emissions. [1] These buildings account for over half of the City of Boston's emissions.[v] Whereas energy efficiency measures are critical to reducing building heating and cooling loads, these measures alone are expected to be insufficient to dramatically reduce or eliminate fossil fuel use within buildings to the level necessary to meet long-term climate goals. **Thermal electrification—the conversion of fossil fuel heating and cooling systems (e.g. systems based on gas, oil, or propane) to efficient electric heating and cooling systems such as heat pumps—is essential for driving building decarbonization and achieving ambitious emission reduction targets in Boston and Massachusetts.[vi]**

Thermal electrification with efficient electric heating technologies can yield substantial emission reductions compared to fossil fuels under today's grid conditions. For example, the Boston Green Ribbon Commission estimates that electrification of space heating in all Boston buildings would reduce building greenhouse gas emissions by 20% using the 2016 electric grid mix. While emission reductions within the commercial sector will vary by building type, they will also invariably scale over time as the electric grid becomes increasingly powered by renewable resources; thermal electrification will reduce building emissions by over 50% with an 80% renewable electric grid. [vii]

Beyond the emission reduction benefits, thermal electrification technologies can also improve indoor air quality and occupant comfort and, in some cases, provide additional amenities to occupants, as well as advance efforts toward achieving building performance certifications like LEED.

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[1] For the purposes to this report, medium- to large-scale commercial buildings refers to municipal buildings, commercial or mixed-use buildings of at least four stories, and multi-family buildings of at least nine units.

However, many building owners and managers lack awareness of thermal electrification technologies or are skeptical about the feasibility of constructing new fully electric buildings, or of converting an existing building to electric heating and cooling. Additionally, poor customer economics inhibit many thermal electrification applications.

This report provides an overview of thermal electrification strategies for large commercial and multifamily buildings in Boston and Massachusetts.

- **SECTION 1** provides a summary of market-ready thermal electrification technologies that have seen significant uptake in the Boston area, specifically, air-source heat pumps (ASHPs), variable refrigerant flow (VRF) heat pumps, and ground-source heat pumps (GSHPs). The section discusses applications and considerations for installation of these technologies in both new construction and renovation projects.
- **SECTION 2** provides an overview of emerging technologies, including hydrogen fuel cells, air-to-water heat pumps (AWHPs), and district ground-source heat pump applications. These technologies demonstrate potential for supporting thermal electrification and building emission reductions but have not yet seen significant adoption in the Boston area.
- **SECTION 3** summarizes several common barriers to thermal electrification in large commercial and multifamily buildings.
- **SECTION 4** outlines potential policy options for addressing market barriers and accelerating thermal electrification in large commercial and multifamily buildings.

The report also includes five thermal electrification case studies of large commercial buildings in the Boston area or in similar climate zones, including projects in commercial office, multifamily, and municipal buildings. These case studies, attached as an Appendix, capture a diverse range of large buildings, including retrofit and new construction installations. The case studies are intended to summarize various thermal electrification configurations and technologies pursued by building owners, outline decision-making criteria for thermal electrification, and summarize lessons learned from existing projects. A full list of case study interviewees is also provided in the Appendix.

EVALUATING COST-EFFECTIVENESS

Cost effectiveness is a key factor for building owners in determining whether to deploy electrification technologies. As owners make capital upgrade decisions, they will typically compare the cost of new technologies with the cost of simply replacing their existing equipment. These cost calculations will include a mix of front-end capital costs, fuel costs and efficiency (electricity vs. gas, oil, or propane for heating, and comparing equipment efficiencies for cooling systems), maintenance costs, and product lifecycles, as well as a value assessment of any non-energy benefits (e.g. added amenities and property value, occupant comfort). Given the wide range of equipment costs, complex HVAC systems, and differing energy needs across Boston's diverse building stock, we were not able to develop detailed cost comparisons between electrification and conventional heating and cooling technologies within the scope of this study. Cost-benefit analyses must typically be done on a project-by-project basis, though future analyses could explore a more in-depth technical and economic analysis (e.g. based on prominent building use cases).

SECTION ONE: MARKET-READY ELECTRIFICATION TECHNOLOGIES

There are currently three primary thermal elec-trification technologies that are market-ready and have been installed in New England in commercial and multifamily buildings. These technologies, summarized in Table 1 below, have demonstrated high performance and reduced emissions relative to comparable conventional HVAC systems. Table 1 outlines the commercial building types for which these technologies are most applicable and the key benefits and drawbacks of each technology, as well as a high-level assessment of technology cost. The remainder of this section explores each technology in greater detail.

TABLE 1: RENEWABLE THERMAL TECHNOLOGIES

	AIR SOURCE HEAT PUMPS (ASHPS)	VARIABLE REFRIGERANT FLOW (VRF)	GROUND SOURCE HEAT PUMPS (GSHPS)
BEST-FIT APPLICATIONS	• Low- and mid-rise multifamily buildings	• Mixed-use buildings • Office buildings • Large multifamily buildings • Hotels	• Commercial and multifamily buildings with sufficient open space (e.g. parking lots)
BENEFITS	• Provides individual unit comfort control with independent systems • Flexible installation options, including using existing ductwork • Operating costs can be directly metered to occupants • Can increase flood resiliency (ductless)	• No mechanical room required • Heat recovery improves comfort and efficiency • Multiple zones operate independently • Reduced maintenance costs • Can increase flood resiliency	• Highest efficiency option for heating and cooling • Reduced mechanical room requirements • Reduced maintenance costs • Long equipment lifetime • Can increase flood resiliency
DRAWBACKS	• Efficiency reduced by cold temperatures • May increase maintenance requirements • Unit electric service upgrades may be required	• Increases demand charges in winter • Requires replacing existing distribution systems • High volume of refrigerants required • Efficiency reduced by cold temperatures	• Requires space to drill boreholes for ground loop • Installed cost typically higher than other heat pump systems • Distribution system modifications may be necessary in retrofits
COST*	• Approx. $3,900+ per ton	• Approx. $8,300+ per ton	• Approx. $12,000+ per ton

AIR-SOURCE HEAT PUMPS (ASHPs)

DESCRIPTION

An air-source heat pump (ASHP) is an electric HVAC appliance that transfers heat between outdoor air and conditioned indoor space to provide heating and cooling. ASHPs transfer heat from outside to inside to heat a space, and transfer heat from inside to outside to cool that space. Like an air conditioner or refrigerator, an ASHP uses a refrigerant compression cycle and heat exchangers to transfer heat, though an ASHP has a reversing valve to allow for both cooling and heating cycles.

For the purposes of this report, ASHPs refer to split air-to-air heat pumps, where each system has one outdoor unit that exchanges heat with outdoor air connected to one or more indoor units, which circulate heated or cooled indoor air, either directly into conditioned space (ductless ASHPs) or through ductwork (ducted or central ASHPs). Split systems are contrasted with packaged systems such as packaged terminal air conditioners (PTACs) and packaged terminal heat pumps (PTHPs) where indoor and outdoor components are combined in a single appliance. PTACs/PTHPs are discussed in a text box below, though this report focuses on ductless ASHPs due to higher performance, installation flexibility, and recent technology advances for cold climate performance.[viii]

Because heating with an ASHP requires drawing heat from outdoor air, these systems have historically not been effective in cold climates like Boston.

**All cost estimates based on median installed costs from projects rebated through the Massachusetts Clean Energy Center's (MassCEC) Clean Heating and Cooling Program. For air source heat pumps, sufficient data is only available for small residential applications, though similar equipment is often used. Actual installed costs will vary significantly on a project-by-project basis. For a description of "tons," and how system capacity is determined by technology see the sidebar on Pg. 8.*

A CLOSER LOOK: ASHP SIZING

The capacity (or "sizing") of an HVAC system is measured in British Thermal Units (BTUs) per hour, which is a measure of how much heating or cooling energy the system can provide in one hour. HVAC equipment that provides cooling is often rated by "tons," where one cooling ton is 12,000 BTUs per hour. ASHPs often have different capacity ratings for heating and cooling due to varying heating capacity at different temperature conditions. Cost estimates in Table 1 for ASHPs are based on heating capacity at 5°F while VRF and GSHP systems are calculated based on nominal cooling capacity (rated capacity based on test conditions from established standards like AHRI and ANSI).

Sizing ASHPs for the space depends on many factors, including climate, application, building performance, occupancy, and personal preference. Proper sizing and equipment selection is critical to maintaining occupant comfort and efficient performance, particularly when being installed in residential buildings with small rooms (and heating/cooling loads).[iv]

However, recent technological advances have greatly increased the efficiency and capacity of ASHP systems in cold climates, enabling cold climate ASHPs to serve as primary or sole sources of heating to Boston buildings.[2] [1] The majority of cold climate ASHPs installed in Massachusetts since 2015 have been duct-less models. [ix]

APPLICATION

In large building thermal electrification, ASHPs have greatest applicability for multifamily buildings where individual unit comfort control is valuable. Additionally, many older multifamily buildings in Boston lack central air conditioning. Ductless ASHPs (and ducted, where individual unit ductwork is available or installed) is ideal for heating and cooling individual building units, as each system operates completely independently of other systems. ASHPs can be installed in retrofits in a phased approach throughout the building (with some disruption to current occupants), or upon unit turnover. In particular, since ductless ASHPs do not need to use the existing distribution system for heating and cooling, the existing central system(s) does not need to be shut down until full conversion is complete.[xi] [3]

Building owners often install ductless ASHPs to add cooling to a space and/or to offset energy costs (especially from non-gas heating fuels), though installing ASHPs can also provide other non-energy benefits. For example, converting an existing building to ductless ASHPs can eliminate the need for central heating equipment, which can improve building resiliency in areas where elevating mechanical equipment from basements is recommended due to present or future flood risk. Ductless ASHPs lack central mechanical equipment and can be protected from flood risks if indoor and outdoor units are mounted above projected flood elevations.

Building owners retrofitting central systems with ASHPs could reduce operating costs by directly metering individual heat pump units, thereby shifting energy costs from building owners to occupants. Added cooling and improved comfort control to units can also be considered amenity upgrades.

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2. Since 2013, the Northeast Energy Efficiency Partnership (NEEP) has certified cold climate ASHPs for residential and small commercial applications based on ability to provide efficient heating (COP > 1.75) at 5°F, among other requirements.

3. Dual-fuel systems are possible, by pairing a heat pump with a conventional fossil fuel heating system, but such systems are out of the scope of this report.

A CLOSER LOOK: PTACS

Packaged terminal air conditioners (PTACs) are heating and cooling assemblies packaged into a sleeve and mounted through a wall. PTACs with heating elements can be connected into a hot water or steam network or rely on electric resistance heating elements. Packaged terminal heat pumps (PTHPs) use a heat pump for heating and cooling, although they typically rely on electric resistance backup when outdoor temperature is below approximately 40°F.

PTACs were adopted because they are easy to install, easy to service, and low-cost. However, they are often loud and inefficient, and their installation requires a large hole in the wall, which weakens the building envelope.

DRAWBACKS & CONSIDERATIONS

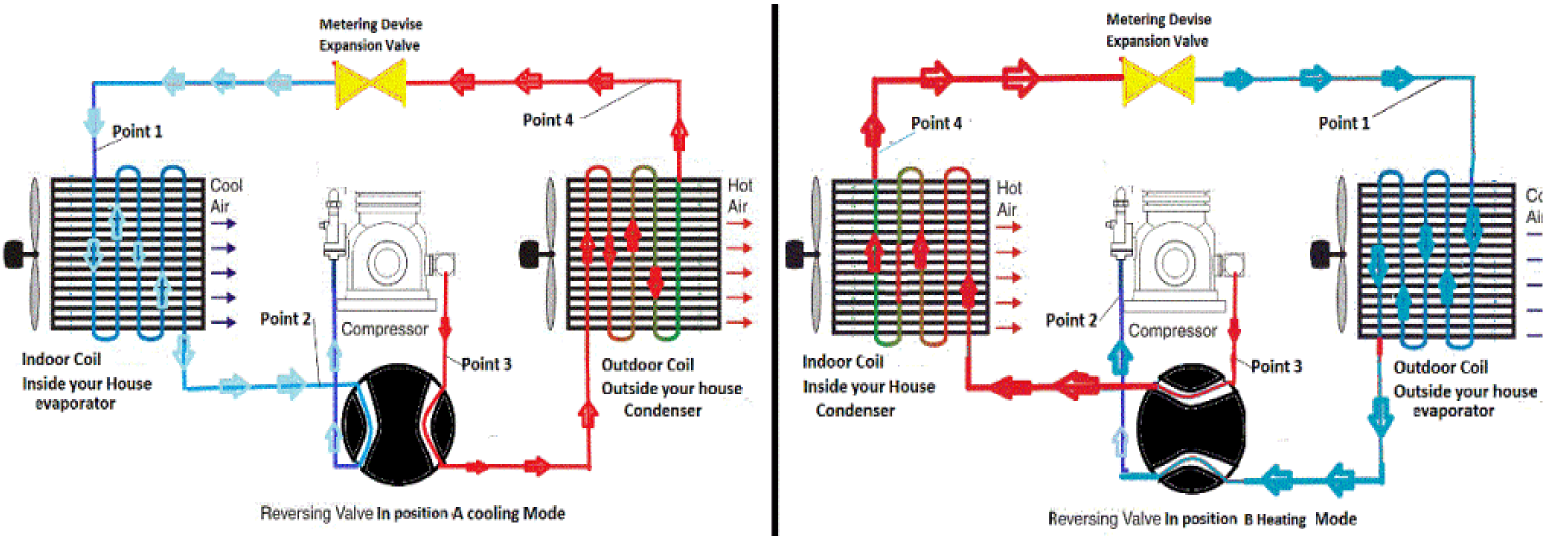
While individual heat pumps require relatively little maintenance, in certain installation scenarios, system maintenance for building owners in larger tenant spaces can be complicated by having to maintain a significant number of indoor units throughout the system's lifetime (i.e. at least one discrete system in each unit as opposed to a single central system).

ASHPs have limitations on refrigerant line lengths between the indoor and outdoor units that can create technical barriers to installation in taller buildings.[xii] While this can be mitigated by placing outdoor equipment in between the ground and roof (e.g. on balconies, exterior walls), building occupants and owners may have aesthetic concerns about ductless ASHP units mounted on the building. Where line length limitations are encountered, building owners may consider VRF systems, which allow for greater line lengths and vertical distance between outdoor and indoor units.

While cold climate ASHPs are available, all ASHPs will lose efficiency as outdoor temperatures drop due to the greater energy required to extract heat from colder air, resulting in significantly higher operating costs in colder weather. Many cold climate ASHPs will retain capacity to 5°F before losing heating capacity, which in the Boston area could result in reduced occupant comfort during the cold-est periods of the year.

Additionally, converting a building from fossil fuel heating to electric heating may require electrical service upgrades in individual units, especially in older buildings.

IMAGE 4



As noted in the Refrigerant Emissions text box, ASHPs use refrigerants that have high global warming potential; systems using refrigerants with lower global warming potential are still uncommon in United States markets.

COST

Based on rebate data from MassCEC and statewide cost studies,[xiii] the median cost per ton of heating capacity for a cold climate residential ASHP in Massachusetts is approximately $3,700, although the median cost per ton in Suffolk County rises to approximately $4,900. Data from commercial ASHP rebates in or around Boston is more limited.[xv] Operating costs are typically higher than gas and lower than oil for heating while having the potential for providing cooling cost savings compared to less efficient systems.

REFRIGERANT EMISSIONS

Heat pumps on the market in the United States today use R410A, R134, and other refrigerants introduced to reduce ozone depletion potential. However, these refrigerants have a very high global warming potential—up to 2,000 times more than CO2. Newer products are under development using refrigerants with lower global warming potential, like R32 and CO2 (R744). However, these products have seen limited uptake in the United States, and are more common in the EU and Canada, which have stronger regulations on refrigerant emissions. Thermal electrification with high global warming potential refrigerants still provides lifetime greenhouse gas reductions relative to fossil fuel systems, but care must be taken to reduce leaks in heat pump systems and to properly dispose of and/or recycle heat pump systems at end of life, in order to minimize greenhouse gas emissions.

VARIABLE REFRIGERANT FLOW (VRF) HEAT PUMPS

TECHNOLOGY

A variable refrigerant flow (VRF) system is an advanced ASHP with a highly adjustable rate of heating and cooling. VRF heat pumps are centralized systems with greater heating and cooling capacity than residential and light commercial ASHPs and can support a greater number of indoor units connected to each outdoor unit. VRF systems are often installed with a heat recovery feature that allows for simultaneous heating and cooling within zones connected to the same outdoor unit, moving heat from one zone into other zones in the building.[4] Heat recovery greatly improves occupant comfort, zonal control, and efficiency in buildings with mixed uses and/or varying loads. [xvi]

APPLICATION

VRF systems are applicable in any type of large commercial building, although the zoned nature of the technology and heat recovery feature is well-suited to commercial, mixed-use, and multifamily buildings with variable loads and a high number of heating and cooling zones. Notably, a VRF system requires no indoor central mechanical space. The outdoor unit(s) can be mounted on the roof or ground, and refrigerant is directed to indoor units through piping that is independent of the existing distribution system. Indoor units can be ductless (e.g. ceiling, wall, or floor mounts) or can be installed to use new or existing ductwork for distribution. Replacing a boiler and chiller system with a VRF system can allow building owners to eliminate the need for a mechanical room, which can increaseusable space and remove the need to elevate existing mechanical equipment in an area that may be vulnerable to current or future flooding.

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4. VRF technology can also be combined with a separate heating/cooling source (e.g. ground source heat pump, boiler/chiller) to distribute heated and cooled air and offer simultaneous heating and cooling across zones of a building, similar to application of a water source heat pump loop.

Because heating with a VRF system requires drawing heat from outdoor air, these systems have historically not been effective in a climate like Boston's. However, similar to ASHPs, recent technological advances have greatly increased the efficiency and capacity of VRF systems in cold climates, enabling cold climate VRF systems to serve as primary or sole sources of heating to Boston buildings. However, there is currently no official standard for defining cold-climate capacity for VRF systems akin to the NEEP Cold Climate standard.[xvii]

DRAWBACKS & CONSIDERATIONS

A key barrier to VRF installation is the timing of installation. VRF systems require new refrigerant lines to be run between outdoor and indoor units throughout the building and do not reuse any existing central distribution. This installation process and decommissioning and removal of the existing system can be disruptive to occupants and can make VRF installation the most straightforward during renovations, tenant space fit-out, or new construction. However, depending on the configuration of the existing system, work can be completed in phases to limit disruption to occupants, given that installation can be completed without leaving areas without space conditioning during installation. Approaches to installing VRF systems in buildings with tenants in place are described in two of the case studies in the Appendix, with the Tarrytown office building and the Carson Tower apartment building.

Additionally, buildings converting to a central electric heating system like VRFs will see a significant increase in demand charges in winter, which could significantly increase heating costs relative to a gas heating system. As with ASHPs, VRF systems become less efficient in colder and as a result, demand issues can be exacerbated by a reduction in system efficiency during extreme cold events.

While all heat pumps currently installed in the U.S. use refrigerants with high global warming potential, VRF systems can require significantly more refrigerant than other heat pump options, which could result in greater undesirable emissions impacts with leakage or improper disposal of refrigerants at the end of life. Manufacturers have begun developing VRF systems that use refrigerants with lower GWP, though these systems are not yet available in the U.S. [xvii]

COST

Data from MassCEC's VRF rebate program indicates that median costs were approximately $8,300 per ton, with installed costs ranging significantly.[xix] For some rebated projects, MassCEC observed that the upfront cost for VRF was lower than that of a traditional heating and cooling system when taking into account the cost of installing a new distribution system.[xx] VRF systems will typically cost more to heat than gas and less than oil, while often offering electricity and demand savings for cooling depending on the conventional equipment being evaluated. Simultaneous heating and cooling may also improve year-round efficiency, though that efficiency is achieved with higher upfront cost.

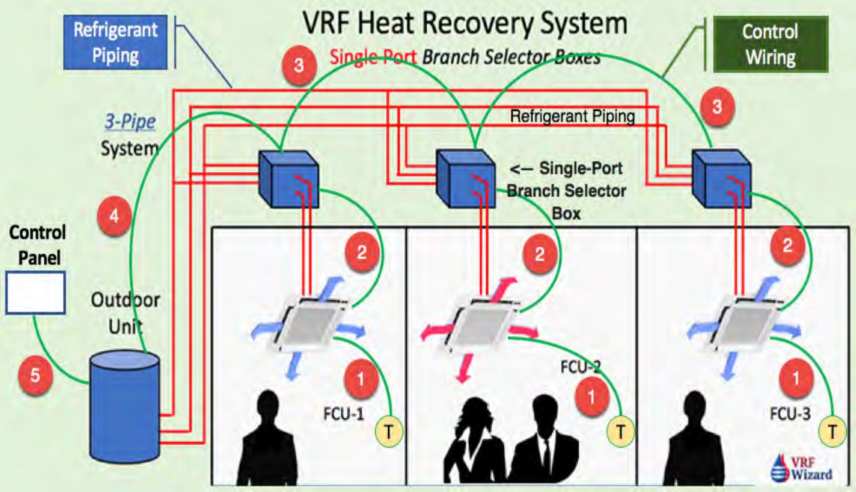


IMAGE 5

VRF System Control Wiring
Wire #1: from the thermostat to the fan coils
Wire #2: from the Indoor VRF Fan Coil to the single-port branch selector box Wire #3: one continuous wire jumping from box to box
Wire #4: one long chain to the outdoor unit
Wire #5: from the VRF/VRV outdoor unit to the control panel
FCU: Fan Coil Unit

GROUND SOURCE HEAT PUMPS (GSHPs)

TECHNOLOGY

A ground-source heat pump (GSHP), also referred to as a geothermal heat pump, uses a heat pump coupled to a fluid loop buried underground that transfers heat between the ground and the building. The system can provide space heating and cooling by circulating hot or chilled water through a hydronic system or by using forced-air ductwork. The benefit of a ground-source heat pump over an ASHP or VRF system is that the ground remains a relatively constant temperature relative to outdoor air, so efficiency of the GSHP system is typically higher year-round and unaffected by lower outdoor air temperatures in the winter.[xxi] Higher year-round efficiency can provide significant demand charge reductions in the summer relative to conventional cooling systems and reduced demand impacts in the winter relative to ASHP and VRF systems. Additionally, compared to ductless ASHP and VRF systems, refrigerants are limited to the heat pump components only, with lower total refrigerant charge and risk of leakage.

APPLICATION

GSHPs require sufficient area on or adjacent to the property for the installation of the ground loop (see callout box for more information on ground loops)—for example, a building with an accompanying parking lot can use the ground underneath that parking lot as space for a ground loop (e.g. as part of resurfacing). GSHPs can generally serve any commercial building that would otherwise use a conventional hydronic boiler and chilled water system. The reduced indoor equipment requirements can free up usable square footage that otherwise would be reserved for mechanical rooms.

GSHPs are also more viable for buildings with balanced annual heating and cooling loads. In very large buildings, there is the potential for consequences from long-term "thermal imbalance." For example, if a building has a significantly higher yearly heating load than cooling load, then the ground temperature of the loop area can change overtime, to the degree where performance and efficiency are negatively affected. This imbalance can be mitigated by using hybrid solutions (e.g. using a backup heating or cooling system for peak days in conjunction with the GSHP system) or adding additional loads to the system (e.g. snow melting, hot water preheating). As long as this thermal imbalance is accounted for, a GSHP can be the most efficient HVAC system possible for an electrified building, with a ground loop lifetime of over 50 years and indoor equipment lifetime of 20-25 years.[xxii]

DRAWBACKS & CONSIDERATIONS

The primary barrier to GSHP installation is identifying sufficient space for drilling the ground loop. Boreholes must be sufficiently spread out to maintain thermal conductivity, and many parcels—especially in a dense urban area like Boston—may not have the space to fit a ground loop on the property (or suitable space may not be easily accessible to a drilling rig). It is possible to drill wells underneath the building footprint or diagonally to reduce space requirements, but the former is typically only feasible for new construction, and the latter is not commonly used in the U.S.[xxiii] In urban areas, ground loops may also have to contend for space with other underground installations, including sewer lines, gas lines, and subway tunnels. A potential alternative being explored is the implementation of a district geothermal network (or geo-micro district), which is discussed further in Section Two.

Installing a GSHP in an existing building with hydronic distribution may also require retrofits to the building distribution system. Most two-and three-pipe hot/chilled water systems circulate heated water at temperatures at up to 180°F, whereas heat pumps (both ground-source and air-source) can efficiently heat water only up to 120°F.[xxiv]

For existing systems that do not use water source heat pump loops (which have narrower temperature ranges), distribution systems designed for higher temperatures will need to be retrofitted as part of the installation (e.g. replacing fan coils) or replaced (e.g. resized hydronic distribution, use of water source VRF for distribution). Integrating a GSHP with existing ductwork may also require retrofits to ductwork.

COST

Based on MassCEC rebate data, median GSHP installed costs were approx. $12,000/ton, though costs varied widely depending on both outdoor and indoor site conditions. Notably, GSHP systems are eligible for a 10% federal business energy investment tax credit, in addition to other incentives.[xxv] The cost to heat with a GSHP is more competitive to gas than other electrification technologies, and significant cooling savings can be achieved as well compared to other technologies.

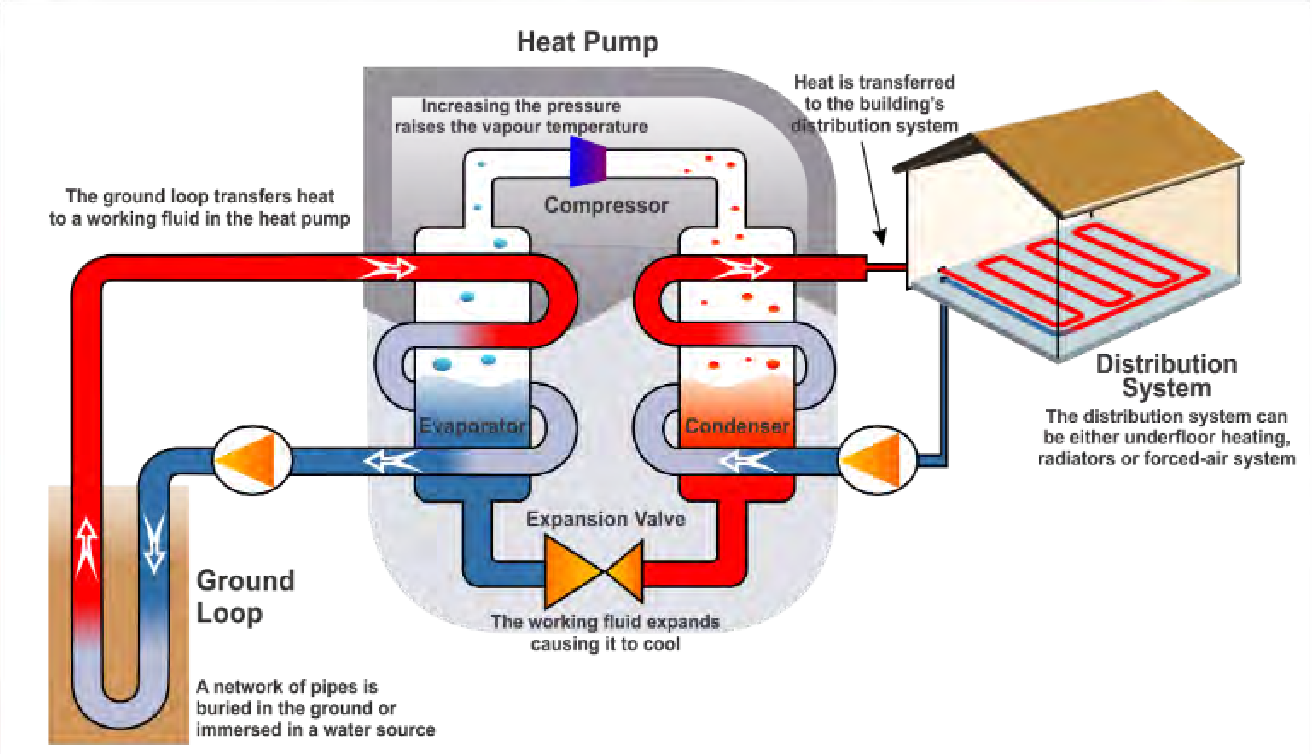
A CLOSER LOOK: GROUND LOOP INSTALLATION

The ground loop of a GSHP can be installed in multiple configurations, including horizontal closed loops, vertical closed loops, and vertical open loops.

Closed-loop systems use a closed loop of fluid buried underground in a heat exchanger coil and can be arranged in a horizontal array (where there is space), or through vertical boreholes. Vertical closed-loop systems account for the vast majority of systems installed in Massachusetts, particularly in large buildings, with approx. 150-200 ft. of bore depth needed per ton of capacity.

Open-loop systems circulate groundwater instead of an internal loop of fluid. Open-loop designs can often be installed at lower first costs, though they require groundwater to be available for circulation and can encounter maintenance issues due to water quality.

IMAGE 6



SECTION TWO: EMERGING TECHNOLOGIES

This section discusses technologies that have the potential to provide or support thermal electrification solutions, though have seen minimal market deployment to-date. While the stage of development varies across the technologies, each currently faces technical barriers that have limited widespread installation in Boston or similar climates.

HYDROGEN

Hydrogen offers a potential pathway for building decarbonization outside of the electrification technologies highlighted in the preceding section. The benefits of hydrogen are that it can be produced without greenhouse gas emissions, potentially stored more easily than electricity, and used to both provide heat and generate electricity. Due to these attributes, hydrogen is considered a potential complementary technology to heat pumps in order to achieve thermal decarbonization. However, technology gaps exist and extensive infrastructure for distributing hydrogen has yet to emerge in the Boston area.

For thermal loads specifically, hydrogen is best suited for larger buildings or campus networks as a potential replacement for gas combined heat and power (CHP) plants. Generating hydrogen through electrolysis[5] and using hydrogen in a fuel cell both generate a significant amount of heat. This can be used to heat buildings, run hot water or steam networks, and provide electricity that can power cooling systems and other electrical loads, like a conventional CHP plant. Hydrogen can also be used to serve heavy industry thermal demands that cannot be met with existing heat pump technologies.

While the technology has promising applications, it also has significant challenges for widespread deployment for decarbonization. Most notably, hydrogen is currently very expensive and carbon-intensive to produce. Currently, the vast majority of hydrogen is produced by steam methane reforming (SMR). In this process, natural gas is broken down into stored hydrogen and other byproducts. However, hydrogen is less energy-dense and harder to transport than natural gas and deriving it from natural gas still produces greenhouse gas emissions. [xxvi] Therefore, steam methane reforming is not a long-term path for using hydrogen to achieve broader decarbonization goals.

Electrolysis, the process of splitting water into hydrogen and oxygen, is the most promising method to decarbonize hydrogen production. An electrolysis system utilizes electricity (ideally renewable electricity) to split water into stored hydrogen and expelled oxygen. This process has significant losses, but it can be deployed to function as an energy storage technology (e.g. using excess renewable electricity to generate hydrogen and using stored hydrogen to reduce peaks for demand response programs), and the heat losses can be utilized for other loads. Stored hydrogen can be used in multiple applications: hydrogen can be injected into natural gas; utilized for high-temperature heat (over 650°C, which heat pumps cannot provide) and for electricity generation; or provided for fuel cell vehicles. [xxvii]

However, producing hydrogen via electrolysis requires large amounts of energy and is currently very expensive. Water electrolysis installations are a nascent market, with projects up to 10MW installed as of 2018.[xxviii] Commercial electrolysis systems are on sale from manufacturers such as Siemens and McPhy.[xxix] Given the current economics, electrolysis is still not a viable method for large-scale hydrogen production to accelerate building decarbonization.

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[5] Electrolysis is the process of splitting water into hydrogen and oxygen

AIR-TO-WATER HEAT PUMPS

Air-to-water heat pumps (AWHPs) are a heating and cooling technology similar to ASHPs, exchanging heat with the outdoor air to heat or cool water, which is distributed through hydronic distribution within a building. The primary barrier to installing AWHPs in the United States is compatibility with existing hydronic distribution. As with GSHPs, AWHPs can only efficiently heat water up to 120°F, while buildings without existing water source heat pump loops are typically designed for hot water temperatures between 160°F and 180°F. [xxx] AWHPs have seen significantly higher uptake in Europe where hydronic distribution systems are typically designed for lower-temperature water. There are high-temperature AWHPs for sale in Europe, like the Daikin Altherma HT and ROTEX HPSU hitemp, [xxxi] which achieve high temperature water by running a two-stage heat pump, effectively coupling a heat pump with another heat pump, which reduces efficiency. Those systems are not for sale in the United States; in fact, few residential or commercial AWHPs are available in the U.S. market. [xxxii]

Because AWHPs are relatively rare in the United States, parts and installation/maintenance experience for the systems are uncommon. There are case studies for AWHPs across the Northeast (and residential-scale AWHPs are incentivized by MassCEC and Efficiency Vermont), but available equipment and uptake has been limited to small buildings. [xxxiii]

DISTRICT GEOTHERMAL

District geothermal in cities is based in principle on campus district geothermal projects such as those installed in the City of West Union in Iowa, Ball State University in Indiana, Weber State University in Utah, and Colorado Mesa University in Colorado. These projects used water loops circulating between multiple buildings to provide heat-recovery-based heating and cooling to mixed-load buildings, with ground-coupled loops used as an additional heat source or sink, depending on campus-wide load requirements.[xxxiv] This configuration provides efficient heating and cooling, and it also allows for expansion with the campus. However, as with individual building GSHP systems, the long-term performance depends on having buildings connected with diverse heating and cooling loads and demands (for thermal balancing).

District geothermal has the potential to address many barriers to individual geothermal installations within an urban context. First, it would consolidate the costs of drilling wells, allowing for the economy of scale offered by drilling multiple wells at once, as well as requiring building owners to manage only the internal heat pump equipment, not the ground loop (which would be owned by a utility, municipality, or other third party). Second, the concern of finding space to drill wells on urban parcels could be mitigated, because district geothermal wells owned by utilities or municipalities could potentially be installed in the existing right-of-way.

However, the financing and business model for larger scale district geothermal networks owned by a third-party is untested. Most district geothermal networks installed in the U.S. to date are on campuses where a single property owner owns the land area on which the wells were drilled and the buildings the geothermal network serviced. Leveraging the support of a utility with existing rights-of-way and the ability to recover costs over the long lifetime of the GSHP ground loop may be ideal for implementation in an urban context with multiple property owners, though the utility business model for such a configuration has not yet been thoroughly explored.

Home Energy Efficiency Team (HEET), a Greater-Boston based nonprofit focused on thermal efficiency, commissioned a study in collaboration with Eversource to assess the feasibility of district geothermal in Massachusetts. The study evaluated the geology and thermal load of Massachusetts buildings and concluded that if closed-loop vertical ground loops were installed in a utility right-of-way, and if the loops were connected in a citywide network, then the network could provide all load to medium-density mixed use neighborhoods and most load to medium-density residential neighborhoods.[xxxv] As a result of the study, NSTAR Gas under Eversource Energy proposed to pilot the installation of district geothermal loops in Lawrence, Cambridge, and Mattapan ("Geothermal Network Demonstration Project") to test technical and business model viability in its Fall 2019 rate case.[xxxvi] The proposal was undergoing public hearing in February and March of 2020, connected in part to the FUTURE Act.[xxxvii]

SECTION THREE: BARRIERS

Thermal electrification technologies face several key barriers that have limited broader deployment in commercial buildings. The primary barriers for commercial sector electrification are related to economics, policy and regulation, and decision-making. However, additional barriers arise from general awareness, technical limitations, and workforce limitations. Each of these barriers is summarized in further detail below.

ECONOMICS

Economic barriers make it difficult for pri-vate-sector actors to justify thermal electri-fication. Despite recent improvements (and limited cost reductions) in technologies, the thermal electrification customer economics are still challenging. Thermal electrification technologies typically have higher upfront costs relative to conventional fossil fuel equipment. This upfront cost differential is particularly notable in retrofit applications without more substantial renovations to the building or replacement of the existing distribution system.

While in many applications thermal electrification technologies can offer cooling operating cost savings, higher heating costs due to the current low cost of fossil fuels can make the overall return on investment of thermal electrification poor or non-existent, which may be unacceptable to commercial building owners. [xxxviii] In commercial buildings with a central electric meter, demand charges can become a significant expense when using heating or cooling at peak times.[xxxix] Demand response, energy storage, and onsite renewable gener-ation (where feasible) can reduce these costs, but these solutions are also expensive to imple-ment under current market conditions.

Cost barriers are reduced in new construction projects, where the installed costs of thermal electrification technologies are typically more competitive with conventional alternatives. This is primarily because both heating and cooling systems as well as new distribution would need to be installed.

POLICY & REGULATORY

Thermal electrification technologies face significant policy and regulatory barriers, which further exacerbate economic challenges. Existing utility program incentive support is currently limited for thermal electrification technologies in large buildings and contends with compet-ing incentives for more efficient fossil fuel appliances.[xl] While states like Massachusetts and New York recently established new statewide targets for total energy savings across all fuels (which enabled utilities to account for and incentivize energy savings from switching between heating fuels where cost-effective, e.g. switching from oil or propane to electric), switching from gas to electric is not currently cost-effective, which has limited the ability for utilities to incentivize thermal electrification. This challenge is exacerbated by the fact that existing markets and regulatory structures do not always value greenhouse gas emission reductions and other environmental benefits provided by thermal electrification technologies (and in the case of the Regional Greenhouse Gas Initiative, costs for GHG emissions reduction related to electricity generation are passed onto ratepayers). [xli]

DECISION MAKING

Decision-making priorities of key building stakeholders can also hinder thermal electrification efforts. Some building owners may have goals that disincentivize building electrification—for example, owners that plan to buy a building and sell it relatively quickly, instead of investing in the property long-term.

Leasing structures can lead to split incentives between building owners and building tenants. If building owners pay for utilities, then tenants receive little benefit for any energy efficiency improvements in the buildings yet would bear significant costs from disruptive construction efforts. Conversely, if tenants pay for utilities, then building owners will see little benefit for investing in energy efficiency improvements. Alternative leasing structures are needed to address these barriers. [xlii]

AWARENESS

Thermal electrification is hindered by lack of awareness of existing technological options. Public policies on energy efficiency have typically focused on high-efficiency fossil fuel sys-tems, so familiarity and experience with thermal electrification systems is low among build-ing practitioners. As a result, building owners may be unaware that thermal electrification is an option to pursue, given that they often rely on recommendations from practitioners on what HVAC systems to pursue. Also, customers that have limited awareness may consider thermal electrification technologies risky investments, citing worries about warranties, durability, and performance that may not always be justified. [xliii]

When an HVAC system breaks down unexpectedly, building managers generally aim for a like-for-like replacement—replacing a broken boiler with another boiler, for example. This action reduces risk, installation costs, and time that the building is missing a heating or cooling system. The greater time investment necessary to plan a more extensive retrofit using thermal electrification makes it less feasible for building owners in need of an emergency end-of-life replacement without significant disruption to tenants.

TECHNICAL & BUILDING

On a technical level, thermal electrification technologies can face several challenges inhibiting their feasibility for certain buildings. First, thermal technology installation can be a highly disruptive process that requires a major overhaul of building systems. Oftentimes, this level of disruption is most appropriate when combined with other major building renovations, such as during tenant turnover, or when property owners/managers think the timing is appropriate for disruptive building work. While strategies are discussed in the case studies in the Appendix that allow for phased installation while allowing tenants to remain in place, such strategies may not meet the needs and constraints of all building owners.

Second, thermal electrification technologies can face challenges integrating with existing building heating and cooling distribution systems. These could include existing ductwork, pipes, and other primary or supplementary heating and cooling systems that are already in place within the building. Enabling effective integration with these systems can add costs and complexity to installation.

Finally, under current development, building electrification technologies have technical limitations that make them inappropriate for certain building types or applications. In particular, electrification of hot water heating (e.g. with commercial heat pump water heaters) in buildings with high hot water demand is challenging given lack of suitable technologies and significantly higher incremental costs.

Beyond the high-level challenges discussed above, Section One of this report outlines further technology-specific challenges that property owners and managers should evaluate when considering the appropriateness of technologies for their properties.

WORKFORCE

Workforce constraints can be a limitation to thermal electrification efforts. HVAC contractors are often unfamiliar with heat pump installation, maintenance, and incentive programs. As a result, many installers also see heat pumps as riskier than conventional systems. Because they are less comfortable installing heat pumps, they will often sell fewer systems and charge more per system to address uncertainty in installation labor costs. Many manufacturers of thermal electrification technologies report that they need to spend much of their marketing budget explaining why electrification is important in the first place, and that contractors often do not install equipment properly. [xliv]

Additionally, switching from a fossil fuel heating system to an electric heating system can be a source of disruption, because use and maintenance practices for the HVAC system change. In many cases, buildings with maintenance staff will need to re-train that staff to work with thermal electrification technologies instead of conventional fossil fuel appliances. [xlv]

SECTION FOUR: POLICY OPTIONS & STRATEGIES

A variety of policies and strategies will be required to address the diverse market barriers discussed in Section Three— **these are not recommendations, but simply a summary of options.**

The options focus on policies that can be implemented by state and local governments—and encouraged by stakeholders in commercial real estate—including adopting practices that reduce **financial risk**; advocating for **measures to improve cost-effectiveness**; and advocating for **codes, standards, and mandates** to accelerate thermal electrification. Table 2 summarizes the high-level categories of policies and strategies available and how they address key barriers outlined in Section Three.

Most strategies that commercial real estate stakeholders can pursue without directly engaging utilities and policymakers include promoting standardization efforts related to

TABLE 2: OVERVIEW OF STRATEGIES TO ACCELERATE THERMAL ELECTRIFICATION

	FINANCIAL RISK REDUCTION STRATEGIES	INCENTIVES & RATE STRUCTURES	CODES, STANDARDS, & MANDATES	OTHER POLICIES/STRATEGIES
POLICY & REGULATORY		X		
ECONOMICS	X	X	X	
DECISION MAKING	X		X	
AWARENESS	X			
TECHNICAL & BUILDING				X
WORKFORCE				X

thermal electrification projects, implementing green leasing strategies, exploring third-party ownership models for renewable thermal installations, and using advanced metering to improve building performance data quality. Further options will require engaging utilities and state and local governments to establish the necessary polices, programs, and structures that support electrification.

Though valuable for enabling thermal electrification in buildings, commercial real estate stakeholders have more limited options for addressing technical, supply-chain, and workforce barriers. These strategies are more relevant for manufacturers and distributors of equipment.

FINANCIAL RISK REDUCTION STRATEGIES

STANDARDIZATION

Adoption of thermal electrification technologies can be increased through a variety of strategies that standardize lending and approval practices to improve cost effectiveness and reduce financial risk. These strategies are varied and include basic lending standards, standardization of design processes and tools, refinement of installation best practices and quality control standards, and development of contract templates. These approaches could be used to not only reduce perception of risk among financial stakeholders, but also to reduce transaction costs for adopting technologies. These types of standards could be developed by a variety of actors within the market, including state agencies, non-profit organizations, and trade associations. Given the heterogeneity of buildings within the commercial built environment, templates and standards will still need to be adapted to each building's circumstance, but common practices and documents will help to streamline this process.[xlvi]

GREEN LEASING

Implementing green leasing strategies is effective for addressing a key source of financial risk - the split incentive between landlords and tenants. Several options exist for re-allocating incentives for energy efficiency investment between landlords and tenants, including passing energy efficiency investment costs to tenants, and placing stipulations on sustainable operations and materials purchasing in lease contracts. Each of these approaches is detailed further in the A Better City report, Energy Efficiency in Commercial Real Estate.[xlvii] Greater awareness and usage of these green leasing strategies would help to alleviate financial impediments for building owners and operators, and thereby support development of thermal electrification markets.

GREEN BANKS

Concern related to financial risk can be addressed further by instituting and supporting "green banks" that provide beneficial financing specifically for projects that advance sustainability priorities. These banks can be charged with understanding the specific risks and risk-mitigation strategies involved in thermal electrification projects, meaning that they will be able to provide more affordable lending products relative to traditional commercial lenders that often perceive renewable thermal technologies as risky investments. The value of green banks for supporting emerging clean technologies has been demonstrated by the New York Green Bank[xlviii] and the Connecticut Green Bank.[xlix]

THIRD-PARTY OWNERSHIP

Alternative ownership and installation models could provide strategies for reducing financial risk. Third-party owners can take on operation, maintenance, and financial risk of thermal electrification technologies, thereby minimizing disruption to the building owners while charging a predictable rate.[l]

There are several companies pursuing third-party ownership of thermal electrification assets. For example, one provider installs, owns, and maintains ground source heat pump loops, connecting the ground loop to indoor equipment owned and maintained by the building owner. This provider then establishes an agreement with the building owner or developer to pay for the installation and maintenance of the system through level payments over time (similar to a power purchase agreement for renewable electricity), which effectively converts a large, up-front capital investment (for a boiler and cooling tower) into an affordable annual operating expense. This may be advantageous for some building owners depending on their circumstance (e.g. reducing capital costs of construction or renovation). The third-party developer is also able to earn a return on investment in this arrangement. [li]

Furthermore, in a 2019 rate case filing, Eversource proposed three Geothermal Microdistrict pilot projects that would provide heating under utility ownership.[lii] These projects would be based on a feasibility study conducted by the non-profit, Home Energy Efficiency Team (HEET), which explores configurations for replacing aging gas infrastructure in Massachusetts with ground-source heat pumps that serve a single street segment.[liii]

SUBSIDIZED THERMAL ELECTRIFICATION FEASIBILITY STUDIES

As noted in the barriers section, many building owners or managers are unaware of thermal electrification technologies and, in absence of government-mandated emissions or energy standards, are unlikely to spend time or money exploring the feasibility of these technologies for their buildings. Providing discounted or free feasibility assessments for properties with high potential for thermal electrification applications to help building owners evaluate the cost and cost-effectiveness of electrification options could be an effective way to incentivize building owners and managers to consider energy efficiency and thermal electrification options. If feasibility assessments demonstrate the cost-effectiveness of electrification, this could also lead to government incentivized pilots of different building typologies in order to develop a robust market for thermal electrification.

METERING

Improved metering can help better manage risk by gathering more accurate and granular data to outline system lifespans and cost-effectiveness in the field.[liv] This information can be provided to building practitioners, building managers, lending institutions, and other stakeholders to better assess the expected financial outcomes of thermal electrification installations.

INCENTIVES & RATE STRUCTURES

The following measures require leadership from utilities and/or governments, although commercial real estate can also engage in relevant forums to advance these strategies.

UTILITY INCENTIVE PROGRAM STRUCTURE

In order to address upfront cost challenges and accelerate adoption of thermal electrification technologies, utility incentive programs need to be able to direct funding toward these technologies at the expense of high-efficiency fossil fuel appliances. This will require utility regulations to properly account for the greenhouse gas and environmental benefits of thermal electrification technologies in program cost-effectiveness testing. Directing the significant funding available through utility incentive programs will improve customer economics and accelerate adoption. The Energy Efficiency Advisory Council, charged with reviewing the state's investor-owned electric and gas utilities energy efficiency Three-Year Plans, could play a vital role in this effort.

Proposed legislation, such as the S2500/Next Generation Climate Bill, could also address these challenges by requiring utilities to include climate risk in all rate making cases and operations.[lv]

RATE STRUCTURES

Beyond incentive programs, adjusting rate structures and instituting carbon pricing could significantly affect cost-effectiveness for thermal electrification. In the current economic environment, thermal electrification technologies may be more expensive per unit of heating than natural gas. However, if fossil fuel prices are increased relative to electric prices, and if demand charges on commercial electric rates can be reduced, then thermal electrification could become much more cost-effective to operate.

Instituting carbon pricing would further incentivize thermal electrification, because electric heating systems can run without releasing carbon emissions (if supplied by renewable resources), whereas fossil fuel systems cannot. Building owners can use thermal electrification as a means of reducing expenses from carbon pricing, or—depending on the implementation of carbon pricing—sell credits from decarbonization as an additional revenue stream.

CODES, STANDARDS, & MANDATES

The following measures could be implemented by state and/or municipal governments, with opportunities for promotion and engagement in relevant forums by commercial real estate stakeholders.

BUILDING CODES & ZONING REQUIREMENTS

Building codes offer an opportunity to encourage electrification in new construction. For example, nearly 80% of Massachusetts communities have adopted the Stretch Energy Code, which establishes higher building energy efficiency requirements for new construction.[lvi] With the Stretch Energy Code expected to be updated in the near future, adoption of a zero net energy or zero net carbon code could encourage developers to pursue thermal electrification in new buildings as a pathway to achieve compliance. Building codes are ultimately subject to federal preemption (to enable building codes to be met with federal minimum efficiency equipment).[lvii]

Additionally, municipal governments like the City of Boston are expecting to expand existing sustainability zoning requirements to incorporate requirements for achieving zero net carbon for relevant new construction projects.[lviii] Similarly, other leading cities such as Vancouver have leveraged the re-zoning process to require new construction undergoing re-zoning to achieve “Near Zero Emissions” or “Low Emissions Green” Buildings standards, which are challenging to achieve when using fossil fuel-based equipment.[lix]

MINIMUM RENTING STANDARDS

Minimum renting standards could be used to require multifamily building owners to electrify buildings over time. For example, England and Wales have instituted a minimum energy efficiency standard for private rented properties, a policy that could be applicable to the City of Boston. Currently, all rented properties are required to have an Energy Performance Certification (EPC), which is rated from A (best) to G (worst) using a standard analogous to Energy Rating Index (ERI) or Home Energy Rating System (HERS). Under the minimum energy efficiency standard, rented properties with an EPC rated below E cannot be marketed or rented to new tenants without retrofit. This effectively is a modification to the building code, but instead of requiring code compliance when renovating a building, this regulation requires code compliance when changing tenants or marketing the property to potential tenants.[lx] The policy went into effect on April 1st 2018, so reports of its effectiveness have not been published as of the writing of this report.

Though the England and Wales legislation does not require electrification, this type of policy can encourage electrification by enabling building owners to pursue electrification as one of a number of strategies to reduce energy consumption and achieve compliance.

NATURAL GAS BANS

Across the country, many municipalities have taken various steps to limit the installation of new natural gas connections and/or equipment in new construction. In 2019, the Town of Brookline adopted such a policy, with other municipalities evaluating enacting similar bylaws.[lxi] In cold climates and for buildings where electrification is not currently technically feasible, such policies could consider a variety of exceptions, such as exempting existing buildings not undergoing major retrofits, large buildings without feasible electrification solutions (e.g. for hot water heating), buildings that require industrial-scale cooking equipment, and other exceptions.[6]

EXISTING BUILDINGS ENERGY & EMISSIONS STANDARDS

Many cities have enacted building energy disclosure/reporting requirements for large buildings, which can also be accompanied by requirements to enact energy efficiency improvements at regular intervals. For example, the City of Boston has already enacted the Building Energy Reporting and Disclosure Ordinance (BERDO), which requires all commercial buildings with at least 35,000 sq. ft. or 35 units to report energy and water use annually and demonstrate reductions in energy use or greenhouse gas emissions every five years.

By heightening program compliance requirements, the City of Boston can use BERDO to indirectly encourage consideration of electrification of thermal heating loads without being prescriptive. For example, New York City notably passed Local Law 97 in 2019, which established emissions intensity (kg CO_2e per sq. ft) limits for buildings subject to the City's existing benchmarking law, which will gradually scale down over time to drive down existing building emissions with substantial fines for lack of compliance.[lxii] Boston is also expected to pursue a similar emissions standard using the reporting pathway established by BERDO.[lxiii] While state or federal action could potentially achieve more far-reaching effects across the state—and few municipalities have enacted such regulations in existing buildings—these standards offer promising opportunities for encouraging thermal electrification as a means for achieving compliance, since energy efficiency measures alone are unlikely to be sufficient to meet the tightening of emissions standards over time.

Expanding the number of buildings captured by BERDO could also increase its impact. Because the program is targeted toward buildings above 35,000 sq. ft, less than 1,800 buildings provided BERDO data in 2019. These buildings are largely concentrated in the Financial District and Fenway-Kenmore areas.[lxiv] [7] The City of Boston, along with other municipalities, could consider expanding existing programs or implementing new programs that target smaller square footage buildings.

OTHER POLICIES & STRATEGIES

Beyond the policy measures outlined above, there are complementary strategies for addressing technological barriers along with supply chain and workforce barriers. Stakeholders within the commercial real estate sector are not best positioned to address

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[6] Notably, the Town of Brookline passed a bylaw prohibiting new fossil fuel infrastructure in new construction and major renovations. However, several exemptions were written into the bylaw, including an exemption for centralized hot water systems in buildings over 10,000 sq. ft. that can demonstrate that no commercially available electric domestic hot water alternative is available that can meet demand for less than a 50% cost premium.

[7] The distribution of BERDO reporting data corresponds to where very large buildings in Boston are built. In the Financial District, there are many high-rise buildings, and in the Fenway-Kenmore area, there are many large educational and health care buildings.

these challenges but can support efforts through partnerships (e.g. collaborating with training providers and utilities to deliver trainings on electrification to facilities staff). Additionally, as discussed above, some thermal electrification technology gaps still remain, with efforts to increase efficiency and utilize refrigerants with a lower global warming potential and develop more technically feasible and cost-effective solutions for electric central hot water heating. Commercial real estate actors can assist in these developments through efforts such as partnerships with manufacturers, along with piloting and testing early-stage technology, where appropriate.

Similarly, the thermal electrification workforce is currently insufficient to meet the installations required to achieve emission reduction targets. Manufacturers and distributors with support from state or utility actors are expected to take a leading role in expanding contractor training and workforce development efforts, but there may be a role for the commercial sector to support training of building staff and property managers.

CONCLUSION

As governments within the Boston area work toward ambitious climate targets, accelerating the installation of renewable thermal technologies will be an essential element of deep decarbonization strategies for the commercial sector. As noted previously, electrification of HVAC equipment can reduce building emissions by 20% with the current electric grid and by over 50% with an electric grid powered by 80% renewable resources, indicating that investing in thermal electrification now will pay dividends as the electricity grid is increasingly powered by renewable resources. Additionally, analyses conducted by New York City and others have demonstrated that deep decarbonization of the building sector is not possible without electrification.[lxv] Recent projects in New England (see Appendix) have demonstrated the ability of ASHPs, VRFs, and GSHPs to cost-effectively provide heating and cooling to a variety of commercial buildings while reducing building emissions and delivering co-benefits from occupant comfort to increased resiliency.

However, for many building owners and operators, thermal electrification opportunities remain challenging to access due to: economic barriers that make large upfront investments in technologies difficult to justify; policy and regulatory barriers that limit provision of the appropriate incentive structures to accelerate technology deployment; split incentive barriers that make it challenging for building owners to benefit from investments in renewable thermal solutions; technical barriers related to the often disruptive overhaul of building systems; and workforce barriers that include both HVAC contractors and maintenance staff wary of new technologies. Additionally, there is an enduring lack of awareness among building owners about thermal electrification options and a lack of familiarity and experience among building practitioners. Given these challenges, it is unlikely that thermal electrification will see widespread deployment in the absence of increased incentives and the implementation of mandates that necessitate electrification.

The large buildings sector must play a vital role in working with state and local governments to develop policies to accelerate thermal electrification. The public and private sector must work together to assess the variety of policy solutions and complementary strategies outlined in this report to identify near, mid, and long-term policies and strategies to pursue. Those developed will ultimately enable the large buildings sector to participate in market transformation and support sector-wide greenhouse gas emission reductions.

APPENDIX: CASE STUDIES

CASE STUDY I: BOSTON UNIVERSITY'S CENTER FOR COMPUTING AND DATA SCIENCES

CASE STUDY II: CARSON TOWER

CASE STUDY III: CONSERVATION LAW FOUNDATION'S BOSTON OFFICE

CASE STUDY IV: TARRYTOWN OFFICE BUILDING

CASE STUDY V: TAYLOR SQUARE FIRE STATION

LOCATION:
665 Commonwealth Ave, Boston MA

STATUS:
New Construction
(Expected Completion in 2022)

BUILDING TYPE:
Higher Education

THERMAL ELECTRIFICATION TECHNOLOGY:
Geothermal (Ground Source) Heat Pump

BUILDING FOOTPRINT:
345,000 sq. ft.
19 stories

CERTIFICATIONS & BENCHMARKS:
LEED Platinum (Being Pursued)
Zero on-site fossil fuel consumption

CASE STUDY I: BOSTON UNIVERSITY'S CENTER FOR COMPUTING & DATA SCIENCES


Rendering by KPMB Architects of new Data Sciences Center

BUILDING SUMMARY

The Boston University (BU) Center for Computing and Data Sciences, owned by BU, is a new academic building currently being built on Commonwealth Avenue, which will include offices, academic spaces, and dining services.[1] This will become the largest zero-fossil-fuel building in Boston, and it advances BU's goal of carbon neutrality by 2040, as it increases campus building area without increasing campus carbon footprint.

The Center for Computing and Data Sciences will use no fossil fuels—instead, its heating and cooling needs will come from a ground source or geothermal heat pump (GSHP) system with 31 boreholes drilled to 1,500-ft in depth[2] and connected in ten independent circuits to improve resilience. The GSHP is sized to 90% of peak building energy load and is supplemented by electric resistance heating and chilled-beam cooling. The building will have no gas connection, so dining services in the building will use electric-only cooking equipment. All electricity used by the building will be matched with energy from BU's wind and solar projects, like the BU wind project being built in South Dakota[3]. Additional planned green construction features include exterior shades to reduce solar heat gain (which reduces cooling load in the summer), triple-glazed windows, and low-to-no volatile organic compounds in sealants and finishes. The first floor of the building is set at 21.25 feet above Boston City Base, which equates to 1.25' above BU's Elevation of Resilience and over 5' above the City of Boston's Sea Level Rise Design Flood Elevation for the site.

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[1] The Center for Computing and Data Sciences does not have an extensive data center.

[2] Most small-scale, vertical geothermal wells are only drilled to 300-600 feet in depth.

[3] Source: https://www.bu.edu/sustainability/what-were-doing/green-buildings/center-for-computing-data-sciences/

DECISION-MAKING

During planning stages, Boston University considered multiple approaches to heating and cooling, comparing conventional and high-efficiency heating, ventilation, and air conditioning (HVAC) configurations against a fully conventional system. This system was chosen because it requires significantly less floor space for indoor equipment than a conventional HVAC system, allowing designers to preserve an entire extra floor as usable space instead of as a mechanical floor.

SYSTEM CONSTRUCTION

Prior to construction, three test wells for the GSHP system were drilled to evaluate different drilling methods by noise, time per well, and cost. The method chosen initially took eleven days per well, but after some time, the drilling team was able to complete a new well every four or five days. As a result, construction was completed ahead of schedule. Identifying a sufficient area for geothermal boreholes is frequently a major barrier for installation, particularly in dense urban areas, but BU identified unconventional locations for boreholes both within and outside the building's lot, including underneath the building footprint. The system did not require permitting beyond standard construction permits required for this type of building, because BU owns all parcels that wells are being drilled on. Existing underground infrastructure has not been impacted by drilling. For heat exchange with the ground the system uses Rygan composite piping, which has a 50-year manufacturer warranty owing to its resistance to corrosion.[4]

Pictured: Drilling of test wells; Courtesy of Dave Green Photography

COST EFFECTIVENESS

The cost and space savings the enhanced HVAC system provides nearly offsets the cost of the well field. Boston University is pursuing Alternative Energy Certificates (AECs)[5] and is working with Eversource to pursue additional incentives. This was achieved at a cost premium well below 1% of construction costs.

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[4] Other common materials for geothermal heat pump piping include high-density polyethylene (HDPE).

[5] Eligible renewable thermal technology installations are provided with Alternative Energy Certificates for useful thermal energy delivered to buildings. Geothermal systems are awarded five certificates for every MWh of energy delivered (approx. $10-15 per certificate) over the lifetime of the system due to their high efficiency.

LESSONS LEARNED

The progress on construction of the Center for Computing and Data Sciences illustrates how compelling geothermal heating and cooling can be for new construction of high-rise commercial buildings—and how the technology can play a critical role in helping BU meet its ambitious climate goals. Because of the scale of the project's heating and cooling requirements, the space saved by using this enhanced HVAC system rather than conventional systems becomes quite significant- in this case saving an entire floor. Additionally, the economies of scale improve the throughput of drilling wells for ground loops, as equipment and staffing can be optimized for upcoming wells.

Boston University expects this project will serve as a proof of concept for future campus projects. The University is sharing this information with the hope of accelerating the adoption of thermal electrification in buildings across sectors, and especially in urban settings where it can inform future development in Boston and beyond.

CASE STUDY 2: CARSON TOWER

LOCATION: 1410 Columbia Rd., Boston MA	
STATUS: Ongoing high-occupancy building retrofit 50% conversion expected by Fall 2020	
BUILDING TYPE: Multifamily Residential	
THERMAL ELECTRIFICATION TECHNOLOGY: VRF Heat Pump	
BUILDING FOOTPRINT: 153 units	

Akelius property: https://www.akelius-properties.us/carson-tower/

BUILDING SUMMARY

The Carson Tower property is a 153-unit high-occupancy multifamily housing building in South Boston owned by Akelius Properties. It is currently being renovated with a variable refrigerant flow (VRF) heating and cooling system while the displacement of existing tenants is minimized. Renovation includes installing in-unit laundry, replacing existing window air conditioning and gas boilers with central VRF heating and cooling, and converting master metering of all building utilities (with utility costs included in rent) to individual unit metering. The building was 90% occupied prior to renovation. In-unit components of the VRF system are being installed as occupants either allow installers into their units or move out.

DECISION-MAKING

Akelius has established common goals for all its multifamily renovation projects, including improving existing rental units to offer amenities similar to condos (e.g., central cooling, in-unit laundry), providing occupants with individual unit comfort control, and improving overall sustainability of their building portfolio—all while limiting disruption to existing tenants. Carson Tower tenants relied on window units for cooling but had very limited ability to control heating in units, leading to some overheating and observed open windows in winter. Additionally, all electrical loads in the building were master-metered, which left Akelius with limited control over managing operating costs.

In other properties it owns, Akelius installed individual ductless mini-split air source heat pumps in each unit so all heat pump energy consumption was metered to the unit occupant. However, given the height of the building and lack of suitable space to place individual outdoor units, a VRF system was more suitable for this project.

The original renovation plan for this project involved retaining existing gas boilers and installing a chiller and water source heat pump loop to provide cooling and individual unit comfort control, but that project plan would have faced zoning issues due to the added height of a cooling tower. With a nationwide pricing agreement in place with Fujitsu, installing a VRF heating and cooling system to meet these comfort goals was a more viable option, even with the challenge of retrofitting while tenants remained in place. Combining this HVAC retrofit with other in-unit renovations to install laundry and individual metering for electricity also allowed Akelius to offer improved amenities while reducing operating costs, as tenant plug loads were eliminated from common electric bills.

SYSTEM CONSTRUCTION

Renovation is being implemented in steps: 1) outdoor equipment is first installed on the roof; 2) indoor distribution is then installed in common areas; and 3) tenant units are then converted to VRF when tenants either allow contractors into their units to make all unit modifications or when the units turn over.

Unit renovation includes installing ductwork and/or ductless air handlers, laundry units, and refitted pipes. Most units receive a vertical air handler (connected to ductwork) installed in a closet, although the smallest units—which have no such closets—receive ceiling ductless units instead. A new utility-owned meter is also installed in the unit along with a user-controlled thermostat, making tenants responsible for their own utility bills. Akelius predicts that these changes will incentivize tenants to use energy more efficiently.

Two contractor companies are currently working on the installation of the VRF system: one is installing outdoor units and indoor distribution equipment for common areas; and the other is installing indoor distribution equipment for tenant units. This arrangement requires significant coordination both between contractors and with the equipment distributor. As some tenants are expected to continue leasing for years and may be reluctant to accept a renovation, some indoor distribution equipment may need to be held by the distributor for up to 5-10 years. Metering for the VRF system will be split, with the electric load of outdoor units and common area components being on the common meter and included in rent, and a tenant's individual indoor distribution equipment load that is connected to the unit's electricity meter,[1] paid by the tenant.

Renovation of a high-occupancy building poses significantly greater barriers than constructing a new building. Any construction work requires 48 hours' notice. It is also impossible to shut down an entire hallway with tenants in-place, leading to some inefficiency in construction scheduling. Additionally, construction is conducted from 9am-5pm to reduce disruption, as opposed to the 7am-3pm hours preferred by contractors, which increases costs by approximately 5-10%[2]. The most disruptive aspect of the construction at Carson Tower, however, is the renovation of ceilings and floors in hallways in order to install refrigerant lines. This produces a significant amount of dust in the common areas of the building.

Akelius estimates that 50% of units will be converted to VRF by Fall 2020. Once enough indoor units are installed (to meet minimum connected capacity on individual VRF outdoor units), the systems can be turned on. Once all the units heated by a given section of the heating system are converted, the boiler can be disconnected for that section and the VRF system can provide heat and cooling to those units.

COST-EFFECTIVENESS

The cost-effectiveness of the VRF system is significantly affected by the conversion from master metering of all building utilities to individual unit metering. Akelius estimates that the building will, on net, use less site energy after renovation. They will pay for a significantly lower load because in-unit electric load costs will be paid by tenants instead of building management. Additionally, rent in renovated units is projected to increase with the improvement of in-unit amenities. As a result, Akelius will see improvements in cost-effectiveness from both lower

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[1] Submetering by heating and cooling load with BTU meters is illegal in Boston.

[2] Many contractors will not accept projects with these hours, citing traffic as a concern.

electricity expenditures and higher rent income, although tenants are expected to face higher costs for energy and rent.

LESSONS LEARNED

Retrofitting a multifamily building with a new HVAC and distribution system without significant displacement of tenants can be more challenging than during full turnover/major renovation, but Akelius' approach demonstrates its feasibility. In a building that needs a full replacement of its air-conditioning system, a heat pump can be feasibly installed as a high-efficiency cooling system with additional functionality as a heating system.

An important success factor for the Carson Tower project has been the careful installation planning prior to construction. The project was expected to take a significant amount of time owing to the slowdowns described above, but by prioritizing time for detailed design work, construction time was reduced due to unexpected complications.

CASE STUDY 3: CONSERVATION LAW FOUNDATION’S BOSTON OFFICE

LOCATION:	62 Summer Street, Boston MA
STATUS:	Renovation (Completed June 2019)
BUILDING TYPE:	Commercial Office
THERMAL ELECTRIFICATION TECHNOLOGY:	VRF Heat Pump
BUILDING FOOTPRINT:	22,000 square ft. 4 stories
CERTIFICATIONS & BENCHMARKS:	Zero net fossil fuel consumption

Photos Courtesy of CLF

BUILDING SUMMARY

Conservation Law Foundation’s (CLF) Boston office is a historic commercial office building owned by CLF. In a recent renovation, thebuilding’s heating and hot water systems were fully electrified. The project was driven by a desire to act in accordance with CLF’s sustainability-focused mission, while also reducing operations and maintenance (O&M) costs relative to the prior system. The building now uses a variable refrigerant flow (VRF) heat pump for heating and cooling. The system manages the thermal load from a small server room. The restaurants on the ground floor of the building are not included in the VRF system.

DECISION-MAKING

The renovation was preceded by 20 years of deferred maintenance. The building envelope needed significant improvement, and most of the prior HVAC system—a gas boiler and chillers—was far past useful life. Staff voiced interest in decarbonization and noted issues in occupant comfort, as many used small space heaters to augment heating distribution issues from the aging boiler. During project scoping, capital costs were deemed a lower concern than O&M costs.

During the planning stages, CLF set full electrification as a priority, and VRF was suggested by the project architect and the builder. The VRF installation was paired with efficiency improvements, including resealing windows, installing LEDs and motion sensors, and replacing the roof with a white roof.

SYSTEM CONSTRUCTION

The CLF Boston office was outfitted with a roof-mounted Daikin VRF system and a basement-installed heat pump water heater. The VRF system has 30 individually controlled zones, each covering four to five offices, and a heat-recovery function. VRF systems typically require replacement of water distribution lines, but because the existing distribution system was already at the end-of-life, this was not an issue. The heat pump water heater was placed in the basement, where its auxiliary capacity to dehumidify improved occupant comfort in the basement locker room.

The VRF system does not have any equipment in the basement, thereby making it resilient to precipitation flooding, the primary climate risk for the office. No backup heating system or storage system was installed. Staff typically do not occupy the building at night, so supplemental heating for overnight periods of extreme cold (and during power outages) was not a concern.

The building was gut renovated between September 2018 and February 2019. The VRF equipment was operational by November 2018, though commissioning and optimization occurred until June 2019. During construction, the entire staff was moved to a rented co-working space.

COST-EFFECTIVENESS

The renovation, including building envelope improvements, roof replacement, lighting replacement, and the VRF system, was financed through a bond from MassDevelopment for a total of $4.5 million. The project included writing off a chiller that was recently replaced for a high cost.

With the combination of improvements, building energy costs are expected to decrease by 10-15% annually, even with the transition from gas heat to electric heat.

EXPENSING DEPRECIATION AS CASH

CLF treats the depreciation expense as an operating expense, for which it fund-raises every year as part of its budget. By accumulating the cash equivalent of the annual depreciation over the lifetime of the asset, CLF will have the funds in hand to purchase a replacement system when one is needed. **Expensing depreciation as cash is vital for managing capital costs for large projects, otherwise capital costs for system replacement are pulled from the system's O&M budget. However, many non-profits do not use this practice, because money allocated to depreciation is not literally being spent as cash.**

LESSONS LEARNED

The renovation of the CLF Boston office demonstrates the economic viability of installing a VRF system in an office building. If paired with efficiency improvements and installed at the end-of-life of the previous HVAC system, then the VRF system will provide reduced operations and maintenance costs after installation, while improving occupant comfort.

Staff report high satisfaction with the performance of the system, as well as with the knowledge that their office is operated with the same sustainability goals that they are working towards.

LOCATION:
Tarrytown, NY[1]

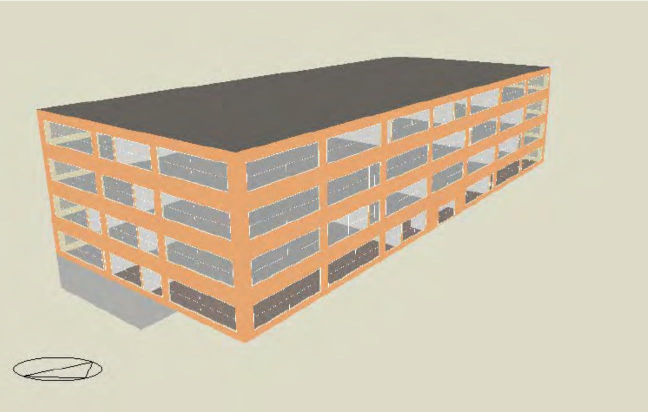
STATUS:
Installation partially completed as of November 2019

BUILDING TYPE:
Commercial Office

THERMAL ELECTRIFICATION TECHNOLOGY:
VRF Heat Pump

BUILDING FOOTPRINT:
71,000 sq. ft.
4 floors (occupied)

CASE STUDY 4: TARRYTOWN OFFICE BUILDING



Rendering courtesy of Fujitsu

BUILDING SUMMARY

The Tarrytown Office Building is located in Westchester County near New York City. During 2019, the building's rooftop-mounted HVAC system was replaced at its end-of-life by a variable refrigerant flow (VRF) heating and cooling system with heat recovery. The retrofit was completed in phases without displacing any tenants and provided significant energy cost savings even when only half-completed.

DECISION-MAKING

The prior rooftop thermal unit (RTU) system in the building was at its end-of-life after 47 years of operation. Because the system was so old, a like-for-like replacement would have required extensive retrofits necessitating sections of the building to be vacated during renovation. The owner was primarily concerned about reducing the original system's high maintenance costs (as energy consumption costs were passed to tenants) but was also motivated by occupant comfort and the prestige of having the best building in the area. Because the existing RTU system was already at the end of its life, the cost of the VRF installation (including incentives from ConEdison) was comparable to a like-for-like replacement. There is currently a moratorium on new gas connections in Westchester County, but the system had been selected and designed before it went into effect.

SYSTEM CONSTRUCTION

The building's previous heating system consisted of four identical quadrants serviced by separate multi-zone RTUs with 10 zones per quadrant. Each RTU was replaced with four multi-zone Fujitsu VRF units, such that each quadrant had over 25 zones, providing occupants with greater control over indoor comfort. Much of the existing building ductwork was reused in the renovation (using mini-ducted VRF indoor units), although additional ductless indoor units

[1] Tarrytown is slightly warmer than Boston annually, with approximately 8% fewer heating degree days. However, design temperature considerations are comparable with regards to system selection and design.

were added. Construction was completed one quadrant at a time during weekends and evenings, so that no tenants were displaced. At most, tenants heard slight construction noise during late afternoons. Building hot water continues to be provided by the existing natural gas system.

COST-EFFECTIVENESS

Prior to construction, annual energy savings for the new system were estimated at approximately $60,000 relative to the previous system. Over an eight-month period between March and October 2019, however, the building saved almost $90,000 in energy costs with just two quadrants retrofitted. Annual savings may decrease during the winter, because electric heating generally costs more than gas heating, even with high-efficiency heat pumps. The VRF system is estimated to have a three-year payback relative to a like-for-like replacement system, even without any envelope improvements made to the building. The capital cost of the new VRF system was partially offset by incentives estimated at approximately $182,000 from ConEdison[2].

LESSONS LEARNED

This building illustrates the high feasibility of VRF systems as a replacement for end-of-life heating and cooling equipment. Depending on the circumstances, a VRF system with incentives can have comparable upfront cost to a like-for-like fossil fuel replacement system. Additionally, the VRF system improves occupant comfort, and in this case did not require any tenants to be displaced, whereas the like-for-like replacement would have required some tenant displacement.

Prestige was a notable motivator for installing the system as well. Not only do renewable thermal systems provide a step toward respected standards like LEED certification, but there is also value to having a modern building with modern HVAC, especially in a city with older buildings like Boston.

Tarrytown is technically in the ASHRAE Climate Zone 4 (Moist), as opposed to the ASHRAE Climate Zone 5 (Moist) in Boston. However, Westchester County is the northernmost county in Zone 4, and it has a climate that is only slightly warmer (by heating degree days) than Boston while still having similar temperature extremes. The equipment installed in Tarrytown, therefore, should remain feasible for Boston buildings.

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[2] Estimation of incentives came from an initial scoping study commissioned by the building owner.

CASE STUDY 5: TAYLOR SQUARE FIRE STATION

LOCATION:
113 Garden Street, Cambridge MA

STATUS:
Ongoing historic building retrofit
Scheduled to reopen in Spring 2020

BUILDING TYPE:
Municipal

THERMAL ELECTRIFICATION TECHNOLOGY:
Geothermal (Ground Source) Heat Pump

BUILDING FOOTPRINT:
Approx. 14,000 sq. ft.

CERTIFICATIONS & BENCHMARKS:
Fully electric design

Photos courtesy of the City of Cambridge

BUILDING SUMMARY

The Taylor Square Fire Station is a historic firehouse built in 1904. Owned by the City of Cambridge, it is currently undergoing a major renovation that includes the replacement of its existing heating, cooling, and ventilation (HVAC) system with a ground source heat pump (GSHP). The renovation started with a roof replacement and envelope improvement. The City of Cambridge then considered the life cycle of other components of the building and determined that the HVAC system was also set for replacement. In accordance with the Cambridge Net Zero Action Plan,[1] only non-fossil fuel HVAC options were considered.

DECISION-MAKING

When evaluating a non-fossil fuel HVAC system, the City of Cambridge conducted a 30-year life cycle analysis and determined that a GSHP was the most viable option as indoor GSHP equipment would need to be replaced less often than rooftop units or outdoor air source heat pump (ASHP) units. Also, a GSHP would have significantly higher energy efficiency in winter months than a comparable ASHP.

Because of a Cambridge policy requiring municipal buildings undergoing major renovations to use fully electric heating and cooling, fossil fuel thermal systems were never considered. Additionally, there was not enough space at the station to consider electric energy storage.

The historic building status of the fire station was not an obstacle for GSHP installation. All the equipment would be either indoors or underground, so the GSHP would not change the building's outward appearance, thereby fulfilling historic preservation requirements.

SYSTEM CONSTRUCTION

The renovated fire station will use three 675-ft wells, each sized to 4.3 calculated tons and installed in the station's driveway at 30 ft apart. The wells consist of a Rygan High Performance Geo Exchange design that is prefabricated and field assembled into one borehole, increasing thermal conductivity by 20% relative to a standard well (excluded from

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[1] For more information, see the Cambridge Net Zero Action Plan.

4.3 tons/well calculation). The driveway previously had an issue with pooling water, which will be addressed by repaving the driveway over the wells.

This ground loop is linked to a water-source variable refrigerant flow (VRF) system that controls distribution of heating and cooling throughout the building. The Taylor Square Fire Station will also include backup radiant electric panels in its upper attic space and electric resistance heating panels in crew sleeping quarters.

The VRF system is valuable to the historic retrofit as it uses significantly less space in between floors relative to ductwork or hot/chilled water piping. Because the system can be run at variable speed, the building's load profile will be adjustable for reducing demand charges while maintaining occupant comfort. Renovation work is currently in early stages, but the fire crew stationed at Taylor Square have been relocated to a temporary station at Mason Square, which is less than two miles from the original site. The temporary station includes trailers for offices and sleeping quarters, and a tent for stationing vehicles. The City determined that phasing construction while keeping the station operational would cost $1 million more than operating a temporary station, and that the noise of the construction would disturb crew members who must sleep in the fire station.

COST EFFECTIVENESS

Having conducted a 30-year life cycle analysis, a GSHP was determined by the City of Cambridge to be the most cost-effective option over the system's lifetime as it would have significantly higher energy efficiency in winter months and require less equipment replacement than a comparable ASHP system. Also, $1 million in savings will result from housing fire crew and administration offices offsite during construction.

LESSONS LEARNED

The GSHP system being installed at the Taylor Square Fire Station illustrates a sensible choice for the City of Cambridge for several reasons: the parcel had clear space for boreholes to be drilled; the 30-year scope of the HVAC life cycle analysis meant the GSHP system was considered more cost-effective over the analyzed time period; and the building was already slated for major renovation, so the significant work required to update its HVAC system was less of an obstacle. Other projects may not have the option to set up a temporary location for the fire station crew and daily operations despite proving valuable in reducing costs.

The Taylor Square Fire Station joins several other City-owned facilities, including the King Open School, Dr. Martin Luther King, Jr. School, and 859 Mass Ave. that have installed electric heating and cooling systems.[2] Lessons learned from this process will support the City's efforts in slowly eliminating fossil fuel combustion from all its city-owned facilities as it approaches its net zero targets.

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[2] Additional information about the King Open School project can be found here: https://www.mma.org/cambridge-school-city-complex-aims-for-net-zero-emissions/. Information regarding the Martin Luther King School can be found here: https://www.brookline.k12.ma.us/cms/lib/MA01907509/Centricity/Domain/62/SCAC%20NZNS%20Interim%20Report%20and%20Recommendations%20%209-25-17.pdf

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lxv. https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/New%20York%20City%27s%20Roadmap%20to%2080%20x%2050_Final.pdf

IMAGES

IMAGE 1. Meeting, http://www.hydronic-heatpump.com/sale-10324542-electric-most-efficient-air-source-heat-pump-ductless-heating-and-cooling-units.html
IMAGE 2: Advantage- Air Systems, https://advantage-asl.co.uk/
IMAGE 3: TLJ Engineering Consultants limited, https://tlj-eng.com/services/
IMAGE 4: AAA Heating and Cooling, https://www.aaaheatingandcoolinginc.com/
IMAGE 5: VRF Wizard, https://vrfwizard.com/
IMAGE 6: Green Match, https://www.greenmatch.co.uk/
COVER IMAGE: Kyle Klein, Kyle Klein Photography