Progress Toward Electrification of Commercial Buildings

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ABSTRACT

Ubiquitous electrification of existing commercial building stock is widely recognized as a "must do" to address climate change. Owners interested in electrification expect HVAC equipment required for electrification to fit neatly and "comfortably" in virtually any existing commercial building that has sufficient electric capacity. Building owners expressing interest in electrification generally expect electrification to be a readily achievable, "low impact" process.

In reality, the building infrastructure requirements for supporting a heat pump system are vastly different from that of buildings designed for fossil fuel heat. The variation becomes even more intensive with buildings that are older, much taller, have no prior air conditioning, or lack ducted ventilation systems. Further, we find owners often can't afford to give up even small portions of useable space in their buildings to accommodate the new type of equipment or associated interconnected pipe and wire.

This paper will provide insights into specific challenges and potential solutions for these hurdles in New England's winter climate. It is also reflective of a high percentage of building stock that is 50 to 100 years old. Creative approaches are being identified that are moving some electrification projects forward. Solutions have some common themes but often require significant customization to fit induvial projects. We are finding phased electrification stands out as a very attractive approach.

Introduction

The Commonwealth of Massachusetts has long been committed to energy efficiency. In 2021, the Secretary of Energy and Environmental Affairs (EEA) set limits on greenhouse gas (GHG) emissions at a 33% reduction from 1990 levels in 2025 and a 50% reduction in 2030. These limits are important milestones towards reaching the goal set by the Global Warming Solutions Act of 2008 which aims to reduce GHG emissions by at least 80% from 1990 GHG emissions levels by 2050. Meeting these requirements will require minimizing reliance on fossil fuels for powering transportation vehicles, heating buildings and generating electricity, as well as industrial and non-energy sources of emissions such as the use and leakage of hydrofluorocarbon (HFC) gases in refrigeration. The use of oil, propane, and natural gas to provide heat for buildings accounted for roughly 30% of the statewide emissions in 2020, making this sector the second largest source of emissions in the Commonwealth. Reducing emissions will require a strong push to increase market adoption of heat pump technologies in homes as well as in commercial, municipal, and institutional buildings, especially those currently using oil or propane which are estimated to be 48% and 19% more carbon intensive than natural gas.

In addition to statewide policy, certain municipalities have enacted ordinances aimed at reducing the emissions of large existing buildings over time. The City of Boston's Building Emissions Reduction and Disclosure Ordinance (BERDO) and the City of Cambridge's Building Energy Use Disclosure Ordinance (BEUDO) require larger buildings to track and report their energy usage and will soon impose fines for buildings that fail to reduce their GHG emissions at a pace fast enough to meet the long and short-term reduction targets. These ordinances are similar to legislations enacted by jurisdictions around the country such as Local Law 97, part of the Climate Mobilization Act, in New York City.

Mass Save® is a collaborative of Massachusetts' electric and natural gas utilities and energy efficiency service providers including Berkshire Gas, Cape Light Compact, Eversource, Liberty, National Grid, and Unitil, collectively referred to as the Sponsors of Mass Save®. The Sponsors provide incentives to help customers implement measures that will save energy and reduce their carbon footprint and their energy efficiency programs will play a crucial role in driving heat pump installations and reducing the GHG emissions in the buildings sector. Committed to decarbonization, the Sponsors of Mass Save offer some of the highest incentives in the country for heat pump installations, as well as funding toward feasibility and technical assistance studies. Eversource is uniquely positioned as the largest utility in the region to be a leader in the decarbonization space. In addition to Massachusetts, Eversource's service territory extends into Connecticut and New Hampshire, states which also are committed fighting climate change and reducing GHG emissions. Experience in three states with different policy, varying energy efficiency budgets, and a diverse customer base gives Eversource perspective on the heat pump market. Eversource has regular conversations with customers (building owners and operators), manufacturers, distributors, contractors, designers, policy makers, and industry advocates.

This paper will focus on trends and observations gleaned from attempting to electrify space heating in existing large commercial buildings. Driven by customer desire to add air conditioning, eliminate oil and propane use as a heating fuel, and the maturity of heat pump products capable of meeting the performance and reliability demands of the market, heat pump adoption has been stronger in homes and smaller commercial buildings.

Larger buildings face headwinds making heat pump adoption more challenging. For example, many facilities utilize hydronic heating systems using a fossil fuel burning boiler to deliver hot water to space at a temperature that is not achievable with current air source heat pump technologies. Where suitable technologies exist, designers may specify more or larger equipment to ensure the system can meet customer needs in the coldest hours and improve resiliency. However, over designing these systems increases implementation costs. Finally, natural gas is the predominant heating fuel used in larger buildings in Massachusetts and the relative cost of electricity as compared to the cost of natural gas can make it difficult to justify the significant capital costs of electrification. Despite these barriers, there are areas of progress. This paper will discuss how customer motivations and environmental policy can affect the decision-making process.

Program Background

The energy efficiency programs provided by the Sponsors of Mass Save have existed for decades, providing value to customers, rate payers, and the environment alike. Customers implementing energy efficiency measures see benefits through decreased utility costs which are used to justify investments by providing acceptable payback periods and prolonged savings. Depending on the measure, customers could also see other benefits in the form of decreased maintenance costs and improved system performance. Energy efficiency reduces energy consumption both at the site and at the power generation source, which reduces pollution as well as decreases the drain on precious natural resources. The shift towards decarbonization has altered the value proposition of program supported projects. Continued efforts to bring more renewables online coupled with improved system efficiencies of heat pump equipment makes electrification an effective strategy for reducing the carbon emissions of energy consuming buildings. While eliminating excessive energy consumption through energy efficiency remains the most effective way to reduce emissions, electrification allows carbon emission reductions on both excess and required building energy consumption and reduces local pollution. As seen in Table 1 below, electricity is the most expensive fuel to consume on site per unit of energy in Massachusetts.

Table 1. Massachusetts Utility Costs

	$/unit[i]	$/MMBTU
Electric Unit = kWh	$0.28	$82.65
Natural Gas Unit = Therms	$1.41	$14.14
Oil Unit = Gallons	$4.09	$30.00
Propane Unit = Gallons	$3.61	$39.45

The relative cost of heating fuels highlights the need to leverage the superior efficiencies of heat pump technologies to realize operating cost savings. Most air source heat pump applications displacing oil or propane will yield operating cost savings but air source heat pump applications displacing natural gas will typically result in higher operating costs for the customer. Massachusetts Department of Energy Resources estimates an air source heat pump will save 20% and 36% as compared to oil and propane respectively while being nearly 30% more expensive than heating with natural gas. Geothermal systems will typically yield operating cost savings regardless of fuel displaced. Where savings can be realized, they are typically not significant enough to provide a payback period within the useful life of the equipment, thus cost savings alone cannot be used to justify spending on electrification as they are used to justify spending on energy efficiency. This change in value proposition resulted in a radical shift in the approach to project implementation and program delivery to leverage better synergies with the motivating factors driving interest in electrification.

Electrification involves replacing entire heating systems. Building owners replace heating systems because they need a reliable heating system. Efficiency and cost savings can be used to justify spending for a more efficient heating system but not the full cost of the heating system. This limits potentially economically viable electrification projects to the replace on failure and aging equipment market. Residential and small commercial customers are more likely to have simpler systems, more likely to be driven by a desire to add cooling, and more likely to be heated by propane or fuel oil, all of which improve the value proposition for these customers. Simpler systems allow for simple program design directly relating the system size to the incentive support and claimed savings. Larger C&I buildings tend to have more complex system designs which make electrification more difficult than replacement of existing equipment in kind. This could include required upgrades to water or air distribution systems throughout the building, upgrades to the electrical service distribution, and structural changes. Implementation costs vary widely and are highly contingent upon the existing HVAC system type, configuration, and equipment and facility conditions, with implementation costs ranging from \$20-\$95/ft^2 for air-source heat pump equipment. Implementation costs for geothermal projects have ranged from \$150-200/ft^2. The total sample size of facilities studied is 40.

Project Experience

The findings discussed in this paper come from experience in helping medium and large commercial and industrial customers explore electrification and decarbonization opportunities at their facilities. From January 2022 through early 2024 we have engaged in conversations and feasibility studies at roughly 80 sites. These sites were self-selected as the interested customers either reached out on their own or through an implementation vendor. Potential electrification projects were identified through our normal sales process with managed accounts we use for energy efficiency measures. In terms of electrification projects, multiple options were explored on a per building basis for customers to electrify their space heating loads currently being satisfied by fossil fuel fired HVAC equipment. These options include full HVAC system replacement with electrified equipment, phased electrification approaches, retrofits of existing HVAC equipment with heat pump technology, ventilation system improvements, as well as hybrid strategies which rely on fossil fuel fired equipment at low ambient outdoor temperatures. The projects are in various stages from feasibility through fully implemented. Some projects are moving through the development. Figure 1 shows the breakdown of sectors in this data set.

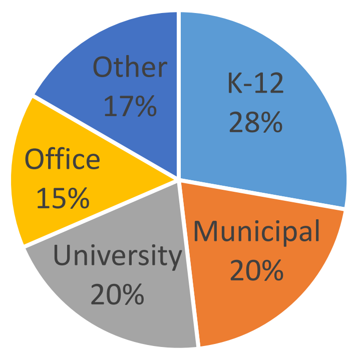

Figure 1. Project data set by sector.

Nearly half the projects are municipal customers, with most being K-12 schools. Cities and towns have shown the most interest which is not surprising given their tendency to own their facilities for long periods of time allowing for a longer-term outlook on building upgrades. Municipalities are also driven by climate target mandates. University customers are the second largest sector to show interest and are also driven by sustainability and can take a long-term approach to decarbonization, however they are more likely to maintain a campus utility plant which adds another layer of complexity. The "Other" sector is mainly comprised of houses of worship and ancillary support buildings such as domestic water pumping stations.

Medium and larger commercial buildings in Massachusetts are more likely to be served by natural gas than smaller commercial and residential buildings. Intuitively, the build-out of the natural gas infrastructure has been aimed at more densely populated areas where most of the larger commercial buildings are located, so it's not surprising that the projects in this data set are heavily tilted towards buildings using natural gas for space heating as indicated in Figure 2 below. As noted above, electrification projects displacing natural gas will rarely result in utility cost savings.

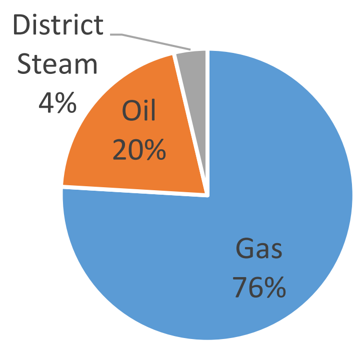

Figure 2. Project data set by fuel type.

Customer Motivations

Massachusetts has been a leader in energy efficiency for decades. It has had award winning demand-side management (DSM) programs and leading-edge Stretch Codes along with BERDO and BEUDO initiatives as mentioned above. As such, the vast majority of large commercial projects customers that have engaged with Eversource are motivated by customer environmental awareness concerns. This is particularly true with municipalities and universities, who are leading in becoming early adopters of heat pump technology.

The college and university projects we are involved with spin out of comprehensive zero carbon plans for the individual institutions with target dates around the year 2050. For these college and university campus projects, electrification of space heating will play a major role in the future, but these projects are being planned across multiple phases. First steps include elimination of extensive underground steam distribution loops, which are the underpinnings of electrification but are a major capital expense.

Eversource is currently engaged with approximately 80 large commercial customers considering electrification of their facilities. These projects are in various stages of development, with most having had electrification feasibility assessments performed or currently in progress. The majority of the projects we are seeing in development are for municipal facilities. Within that subset, a large number of the buildings were built in the early 1900s with some being built in the 1800s. None of the municipal facilities we have completed feasibility studies for were constructed later than the 1970s.

Some of the challenges we are finding with the older buildings include: very shallow ceiling plenums, presence of asbestos-containing material (ACM), lack of vertical shaft space for ducts and refrigerant line sets, inadequate / antiquated electrical services, sensitive historic architectural features, lack of mechanical ventilation systems or mechanical ventilation systems which do not incorporate heat recovery, and deficient thermal envelopes. These challenges all add to the cost of electrification. In addition, where geothermal is being considered, one needs to consider if the building will continue be serviceable long enough derive the benefit to offset the additional cost of the wells.

For the greatest impact, it would be ideal if electrification investments were made with the goal of getting the most carbon reduction possible for each dollar invested. While we don't have the direct experience with studying retrofits to newer buildings, we suspect that the cost per ton of carbon would be lower if municipalities focused on some of their newer buildings within their portfolio.

However, municipalities have not focused newer buildings yet. Municipalities primary focus to date has been with buildings that have other issues with the HVAC systems that need addressing in the short term. These motivating factors include high energy costs, poor thermal comfort, failing equipment, lack of air conditioning, and buildings using carbon-intensive oil-fired heating equipment. So, our observation is that the buildings that might be easiest to electrify might not be the first round of buildings that customers, particularly municipal customers, are interested in addressing. To be clear, we are happy to support electrification for all viable projects, but at the same time, we are driven to reduce carbon emissions as fast as possible.

There is a need in the private sector and for some there is a desire. For example, one private sector project that has completed installation is for a small commercial office building. The project involved removing their aging oil-fired boiler system and DX cooling system and replacing with variable refrigerant flow (VRF) heat pump units. The boiler system was in a state of failure with leaks in the hydronic piping network causing damage to the facility. The customer was able to eliminate risk of further damage to their facility by electrifying their HVAC, and also achieve operational savings with the new heat pump equipment. We have also been involved in two private sector retail projects and have worked on several private sector office buildings including two prominent high rises. For one of these office buildings and for another lab project, the customers have been seriously considering electric resistance heating as a replacement for their fossil fuel fired heating equipment, clearly demonstrating a commitment to taking climate change action, though not necessarily representing an optimal solution from an efficiency standpoint.

Municipal Projects Needing Air Conditioning

Municipalities often pursue electrification when one of their buildings needs HVAC system modifications or upgrades. For example, a design was submitted for a school that would transition it to a hybrid heating system, using both its original heating system and VRF units. The VRF units were capable of providing space heating and cooling, but sized to satisfy the cooling needs of the building. For this project, the desire for air conditioning appears to have been the primary motivator. Given that the space conditioning loads for the facility are heating-dominated, this would require operation of the existing natural gas-fired condensing boiler plant on the coldest days in the year to supplement the VRF system. The design also included installation of a dedicated outdoor air system (DOAS) featuring high-efficiency energy recovery ventilation. The DOAS would eliminate reliance on antiquated unit ventilators and exhaust fans to ventilate the classroom spaces. At the same time, the cost the execute the project was quite favorable in addition to reducing the carbon emissions for the facility This hybrid strategy allows the heat pumps to operate at a more optimal range across their efficiency curve and minimizes risk of performance related issues associated with heat pump equipment oversizing. Additionally, it addresses the customer's desire to add space cooling to ensure occupant comfort as well as and offers an added layer of resiliency by retaining the existing boiler plant and hydronic distribution. Finally, the hybrid design allows for a smaller heat pump system with lower upfront equipment costs and higher capacity operation for the equipment.

Ventilation System Upgrades

Ventilation provisions have emerged as a major consideration in our assessment of heat pump retrofit projects. Several project buildings are so old that they have no mechanical ventilation, which presents several challenges. Since they are not conditioning ventilation air before the installation of heat pumps, there is an even greater heating and cooling load after heat pumps are installed and ventilation rates are increased to code minimum levels. This naturally increases the utility cost penalty of moving from fossil heat to a heat pump. Installing energy recovery ventilators (ERVs) can help reduce these cost increases. Further, some of these buildings are historically significant. Therefore, on the top of adding new systems and duct work, there is a sizable premium on adding them in a manner that doesn't compromise the building's architectural features. In one case, there does not appear to be an appetite for such a visible impact on the show piece town administration building.

School buildings, serving K-12, have also proven to be a challenge on the ventilation side. The buildings typically have classroom ventilation provided by in-room unit ventilators paired with central exhaust fans. Often, control of the ventilation equipment is problematic, relying on aging pneumatic controls and timers. The schools we have been engaged with do not feature more precise measures of ventilation control such as demand controlled ventilation (DCV). One exception is an elementary school that has installed in-classroom ERVs while deactivating their central exhaust equipment and sealing off the outside air dampers on the unit ventilators. This school had already embarked on these conversions prior to exploring electrification.

In all other cases we have examined, the unit ventilators have been heating only, with hydronic or steam coils. We have looked at three different approaches for these unit ventilators. Others may exist but we have not examined them. The most common approach we have taken is to recommend installation of an entirely new DOAS system using energy recovery supplemented by a heat pump coil to deliver room-neutral ventilation air. This strategy completely decouples the ventilation-driven component of a facilities heating and cooling load from the sensible component of the heating and cooling load. This strategy is optimal when considering electrification. Sensible recovery efficiencies of over 85% are achievable utilizing high-efficiency ERVs featuring cross-flow heat exchangers. In the summer, the heat pump coil is necessary to provide dehumidification of fresh air. In the winter, the coil would heat the ventilation air to room neutral temperatures when heat recovery alone is not sufficient. This typically would occur during the coldest portions of a given heating season in the New England climate. Introducing heat recovery therefore reduces the annual heating energy demand from the building thereby reducing the operational cost penalty of going from natural gas fired equipment to electric heat pumps. In cases where a facility is switching from propane or oil-fired equipment to heat pumps, incorporation of heat recovery maximizes operational cost savings.

As mentioned above, a variation on this plan has been proposed. Instead of a central DOAS, individual energy recovery units were proposed for each classroom. The operational cost and energy efficiency benefits are comparable with individual in-room ERV units to those of a central DOAS. Drawbacks to this approach we have identified are that they take additional space in the classroom and may detract from the room aesthetics. They can help where projects need to be phased due to logistical or budgetary reasons, and where space is limited for adding supply and return duct work coincident with adding new VRF line sets, new piping for fan coil units and new.

Another small segment of projects have leaned toward simply using the existing unit ventilators and exhaust fans with no heat recovery. Obviously, this approach has a substantially higher operating cost but was attractive to the owner due to its low initial cost. If full electrification is the goal, this requires the use of heat pump equipment such as air to water heat pumps (AWHP), water source heat pump (WHSP), or ground source heat pumps (GHSP) to supply heating hot water to the hydronic coils in the unit ventilators. In the case of the AWHP, the maximum temperature output of units currently available on the commercial market is 140°F. In cold climates, this might require a hybrid system which relies on a fossil fuel fired peaking boiler to supplement the AWHP during the coldest parts weather of the year to maintain desired space temperature setpoints.

In two cases, customers expressed interest in taking a phased approach to electrification. The initial phase would be exclusively focused on installing a new mechanical ventilation system featuring high-efficiency heat recovery. Phasing was attractive for a number of reasons. The phases could be aligned with energy efficiency grants that are released incrementally to cities and towns on an annual basis. Further, because of the energy efficiency gain from introducing the energy recovery, they capitalize on getting the best economic benefit over the project life span.

One of these towns shared that the mission of their energy committee was to maximize energy efficiency and GHG emissions impacts before embarking on electrification. Completing installation of a DOAS featuring high-efficiency heat recovery as the first phase supports that objective by allowing them to achieve 72% of the carbon emission reduction potential for about 34% of the cost to fully electrify the site. Taking this approach on multiple buildings could yield greater carbon emission reductions than fully electrifying a single building. In a town with multiple schools, and limited budgets, classroom space in three schools could potentially have ventilation upgraded for the cost of full electrification and ventilation upgrades for a single school. Depending on a particular state’s pace of switching from fossil fuel to clean source generation of electricity, it’s possible that energy recovery ventilation as a first phase in more than one school will have a greater lifetime carbon impact than full electrification in a single school. One drawback to keep in mind with this approach is it delays the benefit of adding air conditioning to schools. While this case was not itself an example of electrification, it does demonstrate that getting buildings electrification-ready is a valuable step in the process.

Clarifying the point on phasing DOAS ahead of electrification, the fact that codes require higher ventilation rates for schools relative to other facility types makes this an ideal strategy for school. Other municipal spaces like recreation facilities, which feature a higher ventilation-driven component of the total space heating load, may have similar phased ventilation opportunities.

There is a special case, where schools have two pipe systems feeding classroom unit ventilators featuring a dual function hydronic heating and chilled water-cooling coil. This would be typical in schools which feature and boiler and chiller, where there is a seasonal switchover between the heating and cooling systems (no simultaneous heating and cooling capability). In these systems, the dual function heating and cooling coil is sized much larger than the heating coil in a unit ventilator designed for heating only. This opens up the opportunity to continue to introduce geothermal or air to water heat pump system, which can provide both heating and cooling via the existing unit ventilators. The first cost savings associated with the ability to retain the existing hydronic/chilled water piping system and terminal units would be highly favorable. One tradeoff would be that the unit ventilators, in nearly all cases, would not have energy recovery. In our climate zone, the ventilation driven component of the heating load for a school is upwards of 40% of the total heating load for pre-1980s school building. As such, there is a substantial energy cost premium for reusing the existing UVs for ventilation as the source of ventilation.

While we have not encountered this specific configuration, it is possible that a building such as this could be retrofitted with a DOAS system. Then, the once through exhaust could be terminated by sealing off the unit ventilator intakes, essentially converting the unit ventilators to fan coil units. Since these two systems are independent, this work could be staged as two separate projects over time to make the change to spread out costs or to align with grant funding availability.

Desire for Back Up Heating Systems

Several customers have submitted projects where they are not willing, or able, to rely on heat pumps as their sole source of heat. There are many legitimate reasons for this, such as for schools which double as warming shelters and so are not inclined to upsize their emergency generators to power the heat pumps. Other schools have insisted that the existing heating system be left in place for freeze protection when power is lost to run on the existing generator. While this is a reasonable approach, it introduces a number of issues. Where there is oil heat, the stored oil does not remain stable for long periods of time. This can create an added O&M burden for the backup system due to the requirement to maintain a fresh fuel supply. Additionally, there is always the risk of potential leaks in the oil storage tank which could result is costly remediation efforts. Whether the backup system utilizes natural gas or oil, the owner will need to not only perform O&M on the existing fossil fuel fired system, but the new heat pump system as well, adding another potential layer of O&M costs. Further, there is an expense for maintaining a backup system exclusively for operation during extended winter power outages, and at some point, the need to replace the backup system. As mentioned previously, many customers have been motivated to replace equipment that is approaching the end of its useful life, so relying on such equipment as a backup system could be problematic.

As just stated, retaining fossil fuel-fired systems only for emergency use might not be favorable. There is an alternative approach to assuring fossil fuel fired heat is available for adverse situations. In fact, having fossil fuel-fired equipment and heat pumps serving the same building can be a beneficial combination if intentionally designed as a hybrid system. Here, the fossil fuel-fired system is operated only during the coldest temperature bins, starting around 15°F to 20° F. It has been suggested that this would leave on the order of 20% of the annual heating load on fossil fuel. Achieving this, though, requires a fossil fuel-fired heating system that can meet the design load for the building if full redundancy is a requirement.

That said, the heat pump system is sized smaller since it gets shut off at around 20°F (switchover temperature). Purchasing less capacity reduces the cost of the heat pump equipment for the project and offers the benefit of adding space cooling where it may not have existed before. At the same time, you improve the annual efficiency of the heat pumps since the annual coefficient of performance (COP) is improved by eliminating operation during the coldest hours of the year. The obvious heat pump equipment type for this would be air to water or a GSHP system plumbed in parallel with a fossil fuel fired peaking/backup boiler plant, sharing the same hydronic distribution system. There are retrofit kits available for air handling units (AHUs) and roof top units (RTUs) that have gas furnace sections that can be operated this way as well. These kits replace the existing cooling section of the unit with a heat pump coil, which is serviced by a VRF outdoor unit (ODU). Another strategy is to retain the existing boiler plant and associated hydronic distribution and terminal units and install an entirely separate VRF system sized for the desired switchover temperature utilizing an integrated controller to switch between the systems. We have been involved in projects that have looked at using VRF equipment as described in conjunction with an existing boiler plant. There has also been a project completed for a library that uses air to water heat pumps that is tied to an existing gas fired hydronic system. This project was able to be installed without significant updates to the hydronic distribution and terminal units at the facility, and will displace approximately 80% of their natural gas consumption at the site. Additionally, the new AWHP has served to replace a failing air-cooled chiller, therefore there will be an improvement in cooling system performance as well.

Applications by Equipment Type

Since the inception of our building decarbonization efforts, we have provided incentives for hundreds of VRF units and air source heat pumps. We have one retrofit air to water heat pump, that has been involved in our program installed and operational, for a library facility previously discussed. We are currently in discussions with several customers working to install GSHPs.

VRF has been attractive for a variety of reasons. Generally, it has a lower first cost than air to water or GSHPs. It also is more efficient than the air to water so there is a lower annual operation cost. It also can require less mechanical room space, unlike AWHP or GSHP projects which may require buffer tanks, however it VRF equipment will require sufficient space on rooftop or a grade level for the outdoor units. Consideration must be paid both to potential aesthetic impacts as well as the structural integrity of the roof assembly. Space for new equipment can also be an issue if there is a need to phase the project in a way where both the existing fossil equipment and new heat pump equipment need to operate simultaneously for a period of time.

There are heat pumps configured as packaged roof top units (RTUs), but for cold climate applications these are typically configured as hybrid units with either an electric resistance heating element or gas furnace section incorporated into the unit. In order to get significant decarbonization benefits out of these systems, the RTUs have to be the primary heating source for the space they serve, and the space needs to have a significant heat load. In our experience, these are suited for single zone constant air volume applications where there is no supplemental heating system, such as a perimeter finned tube radiation. Multizone variable air volume systems are less well suited to heat pump RTU retrofits with respect to decarbonization, as these systems often feature electric resistance or hydronic reheat coils at the terminal units. In our research, these reheat coils often carry a high percent of the heating load as compared to the RTU itself, therefore lowering the decarbonization potential of the new heat pump RTU equipment.

Many might ask why someone who didn't have a significant heat load would pay the higher cost for a heat pump primarily for cooling rather than installing a gas or electric resistance unit. For us, having a very generous incentive program could drive a customer to purchase heat pumps even if it provided little or no carbon reduction benefit. Those involved in incentive programs with audited results will be well familiar with the challenges of setting program eligibility criteria that closes loopholes, such as this.

There are retrofit kits that can be used to retrofit heat pump coils to existing air handlers. These can be an optimal solution for air handling equip under 15 years old. These are proprietary engineered solutions offered by several major equipment manufacturers that require close work with the selected manufacturer. They can be, and often are, installed in series with a gas furnace section or hydronic heating coil. The kits replace an existing DX or chilled water coil in the air handling unit, incorporating a new linear expansion valve to allow for the coil to provide both heating and cooling. The other component of the system is a VRF outdoor unit which is connected via new refrigerant line sets to the new heat pump coil and linear expansion valve. In the case where a critical component of an air handling unit fails and necessitates replacement of the entire unit, the VRF outdoor unit and other system components from the retrofit kit may be retained and utilized in the new air handling unit. Where you have a high percentage of outside air and no energy recovery, the availability of a backup heating section (electric resistance, hydronic, or gas furnace) can ensure continuous delivery of room neutral temperature air even while the heat pump section goes into defrost mode. We have only been involved in one project where these were recommended, so we have more to learn about them. That said we do understand they are becoming increasingly popular in New England and as such we are actively working to advance these applications for our customers. The same cautions apply here as apply to RTU heat pumps.

Air to water heat pumps have, thus far, proven to be far less popular than VRF equipment and even less than GSHPs. On the surface this may seem illogical. The vast majority of modern building in our service territory have hydronic heating systems. This suggests that the distribution system including, pumps, piping, coils and emitters are already in place. There are two main obstacles that counter this thinking. In many cases, particularly in older municipal buildings, the existing piping and fan coils are in poor condition due to corrosion. This undermines the advantage or reusing the distribution system.

The second obstacle relates to the current state of heat pump technology. During the period of our work on these projects, the high end of the output from a water source heat pump has been in the 130°F to 140°F range. With our retrofit work to date being exclusively focused on older buildings, this supply temperature is a barrier. The existing heating coils, emitters and the pipe sizes are designed for higher supply water temperatures in the 160°F to 180°F range. This eliminates or greatly undermines the opportunity to reuse existing equipment. Replacement equipment that can satisfy the same loads with lower supply water temperatures is available, but clearly has a major impact on the project cost.

An opportunity does still remain for these buildings, but it does not enable 100% electrification. Where the existing distribution is in good condition it is possible to connect AWHPs in parallel with an existing fossil fuel fired boiler plant. In such a hybrid approach, the heat pumps can carry the heating load until the outside air temperature drops to the point where an adequate supply water temperature can only be achieved by activating the fossil fuel fired boiler plant. The first drawback to this is that the customer is still maintaining a fossil fuel fired system that can meet the maximum building load. The additional system incurs extra O&M as well as capital replacement costs. When it is time to replace the existing boiler plant, it may be possible to downsize to boiler equipment sized for peaking purposes only, provided this meets the customers resiliency requirements. Second, with a fossil fuel fired boiler system in place, in particular for natural gas fired equipment, the full heating load can be met at any time at a lower utility cost using the boilers than the heat pumps. Management must continuously make sure that all facilities staff understand that heat pump operation is the priority, and that controls sequences are in place to prioritize the AWHP equipment as the first heating stage. Now, early in 2024, HVAC manufacturers are talking about products coming to the US market in the months ahead that can deliver higher supply water temps, closer to 160 degrees. These new products may expand the market for air to water heat pumps in existing, serviceable, hydronic systems.

Dedicated Outdoor Air System (DOAS)

Total building electrification is increasingly popular, most prominently in the Zero Energy Space. DOAS systems with energy recovery ventilation are a prominent feature in these buildings because of reduction of the ventilation driven component of the heating load. For the same reason, DOAS is ideal for retrofit electrification projects from a performance standpoint. That being said, we have navigated concerns about the fit for these systems from an applicatory standpoint in retrofit applications. Prominent concerns include low ceiling heights, shallow ceiling plenums, conflicts with PV systems for roof space for equipment and ductwork, and excessive disruption of building occupants and finished surfaces within the building, particularly if there is insufficient shaft space.

The disturbance of occupants may be less of an issue in K-12 schools which may take summer breaks. That said, several school facilities managers have stated they don't have confidence that a project of this magnitude could be completed during the summer break. To avoid this, a project might be phased such that ductwork is completed at a different time than the piping and wiring for the heat pumps, but there could still be a substantial increase in ceiling and general conditions cost. Coordination of location of equipment in ceilings and shafts might also become an issue.

In another instance we have begun to examine retrofitting an existing office building from VAV to heat pumps. The existing building is over 100,000 SF and is 4 stories. It only has four roof mounted Air handlers. There is a concern that the existing duct work would need to be removed or at least partially deconstructed in order install the vertical ductwork in the existing shafts for a DOAS system. That would disable the HVAC to 25% of the space during construction. The space could not be occupied during that time if the work could not be completed within roughly a three-day window. It's possible that in this situation, or others that are similar, temporary relocation of staff would be required. This would add substantially to the cost of the project.

Applications by Facility Type

High Rise Office Buildings

We have had the opportunity to examine projects for two high rise office buildings. These present unique challenges. The most obvious challenges are small roof areas relative to the building square footage, which can be a constraint for how much equipment can be installed. There can also be challenges to getting equipment to the roof due to limitation on crane access. Available shaft space for wiring and line sets or piping in a high rise is also an issue. In one project there were options to install a heat recovery chiller and to install VRF units. The heat recovery chiller was only able to provide a portion of the load but it proved to be attractive financially because it had no construction impact on occupied spaces and because the building had been originally designed for a heat recovery chiller that was apparently a victim of value engineering. Alternatively, a VRF system was suggested for the building, but it was limited to serving only the top half of the building due to design limitations on the length of the refrigeration line sets, which is a factor for all VRF equipment at this time.

One high rise customer already had water source heat pumps installed with the water loop being tempered by a boiler and a chiller. Current air-to-water heat pump technologies can meet the design requirements to provide the 70- to 90-degree Fahrenheit water, even on the coldest days of the year. However, designers still feel the need to provide resiliency with a backup system because of lack of confidence. Furthermore, installing the heat pump in the existing penthouse mechanical room would require an additional $8 million in customer side electrical work. The customer explored putting the heat pump in the garage to significantly reduce the electrical infrastructure cost, but this would require the losing parking spaces which are a real commodity in densely populated areas. Other creative solutions were considered as well, including partial electrification of the space heating equipment. Ultimately, however, the costs were staggering compared to the low decarbonization potential. Despite being a 19-story building over 600,000 sq. ft., the boiler consumed less than 7,000 therms annually. This yielded a cost of approximately $14,000.00 per metric ton lifetime CO_2 emissions reduction. For comparative purposes, the average cost per metric ton lifetime CO_2 emissions reduction across all building segments studied is $1,250.00 per metric ton lifetime CO_2 emissions reduction across a sample size of 40 facilities studied.

College and University Campuses

A respectable size set of higher education campuses have taken interest in electrification. The Commonwealth of Massachusetts has boldly begun an investigation of district geothermal plans for several state university campuses, one of which we have been involved in. The balance of our experience has been with private colleges.

Most of the state schools are looking at geothermal heat pump systems as a specific tool to achieve their climate change goals. Also in the mix is a private school where capital funding is tight and capital demands are numerous. Our work examining solutions for this customer is just getting started, but it is worth mentioning because this project illustrates many of the challenges of decarbonization. Their campus includes classic New England brick buildings from the early 1900s, with expansive operable single pane windows. In terms of climate impact, this is an excellent candidate project. It would leverage major efficiency gains by addressing losses from aging underground steam and condensate lines, with further savings from eliminating reliance on opening windows as the primary means of temperature regulation in dorm buildings. And for a customer with tight capital constraints the potential for utility incentives, along with the potential to introduce air conditioning to these buildings raises interest in a heat pump retrofit.

These potential projects have both very strong decarbonization projections and customer motivation. Success will depend on overcoming the hurdles outlined below.

1. Customer need to replace aging steam boilers in timely manner.
2. Some projects involve dorms that must have heat, even in a power outage.
3. Lack of existing ventilation; new system trigger code requirements.
4. Existing windows perform poorly and would lead to high heating loads and high operating costs for the customer after the retrofit.
5. Uncertainty of campus electrical service capacity. The cost or the timeframe for an upgrade, could upend a heat pump conversion.

Exploring all these questions is time-consuming for the institution’s facilities staff and requires significant investment in engineering and cost estimation. These up-front demands go far beyond what would be required for most fossil fuel-based solutions that might also be under consideration in projects such as this.

By contrast, other institutions we have encountered already have strong support for decarbonization, regardless of the types of hurdles described above. For all the campuses we have assisted, aging district heating infrastructure has been a primary motivator for change. Several had taken the initiative to create well-detailed master plans for the conversion off of steam and fossil fuels extending out 20 years plus. These projects include tens of millions of dollars in spending on piping replacement, modifications to HVAC terminal units, building controls, and in some cases new heat pump chillers and boilers. As such, actual electrification phases like the installation of heat pumps can be many years in the future. In such cases, these very large projects, may not count toward utility decarbonization goals as quickly as we would like.

In these plans we see several steps, often reaching over decades to reduce fossil fuel use. There are institutions that have existing combined heat and power (CHP) plants that carry a portion of the heat load. In this case the plan calls for continuing to use this asset for part of the heating load for many years while at the same time adding GSHPs to reduce the load that was carried by boilers that worked in parallel with the CHP. The common approach we see is replacement of underground steam piping with hot water piping. It's typical that the first phase is primarily replacement of the hot water piping, which is very capital intensive. In the first phase, we see plans to continue. We currently are involved with four such projects all of which have steam boiler plans and rapidly deteriorating underground distribution systems.

So overall, higher education campuses may be leaders in setting zero carbon targets, and creating master plans, but much of the actual decarbonization impact may be years in the future for some.

Challenges

Across all commercial building segments studied, some common themes were identified in terms of challenges facing owners as they move forward to electrify their facilities.

Potential challenges to electrification of commercial buildings include:

1. Inadequate electrical infrastructure/service on site
2. Inadequate mechanical ventilation
3. Absence of airside heat recovery, in particular for schools with unit ventilators
4. Lack of available space for new mechanical equipment and air/water distribution
5. Existing hydronic infrastructure designed for high temperature water, and limitations of temperature output of commercially available heat pump equipment.
6. Significant disruption and disturbances to occupied spaces
7. Structural upgrades to support weight of new equipment
8. Presence of hazardous materials such as lead and asbestos
9. Limited windows of time for construction (schools, laboratories)
10. Significant building envelope deficiencies which must be addressed due to the lower temperature output of heat pump equipment relative to fossil fuel fired equipment.
11. Refrigerant changes which will necessitate additional leak detection/monitoring equipment for VRF systems.
12. Distribution systems well beyond useful life (example, corroded hydronic mains)

Solutions

True solutions can only be claimed after systems are installed and results are measured. The first two projects we have assisted developing have just been completed, so at this stage we can talk about the concepts that we have recommended that have shown the greatest promise, including those that make buildings electrification-ready:

1. Small capacity VRFs combined with ERVs operating in conjunction with existing fossil fuel heating systems can achieve the benefit of adding air conditioning while electrifying the heating load during the portion of the year when VRFs are most efficient.
2. Air-to-water heat pumps added to existing hydronic heating system to partially electrify a building with no need to modify existing terminal units. The heat pumps operate with a higher seasonal efficiency by switching to fossil fuel systems for the coldest hours.
3. Partially electrifying a single school, instead of fully electrifying a single school by installing dedicated outside air systems with energy recovery to electrify the ventilation load. This emphasizes the importance of conservation first and delivers more carbon savings for approximately the same cost.
4. Retail settings, where simple systems are more prevalent, have had some success in electrification. Single-zone heat pump RTUs require no changes to existing controls or air distribution, no additional space, and no construction work in occupied areas.
5. Inflation Reduction Act (IRA) funding is emerging as a driver for geothermal projects, upscaling municipal interest to this more efficient technology in lieu of VRF equipment.

These solutions can help drive adoption of electrified solutions in the near term for some projects while setting up other buildings to be able to reduce or eliminate fossil fuel consumption at a more opportune time in the future.

Conclusions

Heat pumps, and the subset classified as VRFs, have been in the marketplace for several decades. They are a well-known technology to engineers and contractors. Arguably they dominate the market for zero energy and zero carbon buildings in cold climates. Despite this provenance, there is still a lot to be learned about applying them in a full range of existing buildings. Further, our own work has identified ways to unlock many of the common barriers to applying them in many common building types and building system types.

While there isn’t yet a wide-ranging interest in installing heat pumps in larger commercial buildings in the Northeast, there are early adopters who are willing to face the financial and practical barriers. There will need to be a major shift in thinking for building owners and taxpayers towards a willingness to pay higher utility costs and, in many cases, quite substantially more for HVAC system replacements for these systems. Technology limitations are also an issue. For example, many office buildings we serve use hydronic reheat that may not operate at their maximum water temperature if heat pumps serve that load.

This said, we are early on the path to a significant conversion of the commercial and industrial building stock in New England over to heat pumps. We have seen advances in technology and are finding creative was to make more of these projects viable. Notably, we have seen increasing interest in geothermal systems in recent months. In the first year, interest was centered around large university campus settings, but it is now shifting to municipalities. Most promising, we are starting to see our first large projects coming online.

We continue to watch market conditions, and as advancements are made, we will be able to serve a larger segment of the market more cost-effectively over time. To continue to grow this market, we can lead the way by continuing to find cost effective ways to deploy heat pumps in different building types and building systems. While waiting for market conditions to improve, we will increase customer and designer awareness of electrification opportunities.

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