The Present and Future of Decarbonizing through Electrification in Commercial Buildings in the Midwest

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ABSTRACT

The U.S. building industry is not on track to decarbonize fast enough to avoid dangerous levels of climate change. The Midwest is a microcosm of this broader issue because of its near-universal natural gas availability, high electricity cost relative to natural gas, extreme cold weather, and less-progressive regulatory environments than the coasts. However, there are paths forward. This paper describes five typologies that deserve strong consideration for action on near-term electrification of heating in the Midwest:

1. Mid-sized commercial new construction
2. Multifamily new construction
3. Rooftop unit (RTU) retrofit
4. Retrofit of in-unit systems for multifamily/lodging
5. Retrofit of centralized systems

This paper describes each typologies' electrification technologies, as well as barriers and solutions to deployment at scale. We lay out observations and data we have collected from studying and piloting electrification in the region. We discuss best practices for building professionals and other industry stakeholders, both for those at the forefront of electrification in the Midwest and more mainstream stakeholders. We also identify cross-cutting recommendations that require coordination among multiple actors to transform the market.

Introduction

Heating electrification in the commercial sector, likely due to the relative complexity of its existing mechanical systems, is lagging the residential sector. Commercial heating electrification is moving forward on the West Coast and in the Northeast due to policy interventions. In the Midwest, a moderate regulatory environment, coupled with natural gas availability, high electricity rates relative to natural gas, and extreme cold weather are hindering deployment of electrified heating systems.

Slipstream and RMI are investigating solutions to electrifying the largest fossil-fired end use, heating, in several applications. Given the complexity of both building type and existing heating system type, our investigations have initially targeted typologies that share near-term promise and a need for solution development. This paper describes the barriers and solutions across several of these typologies. We lay out our data and analysis from observations of the market and in the field. We discuss best practices for building professionals and other industry stakeholders, for those at the forefront of electrification in the Midwest and mainstream stakeholders planning to implement decarbonization efforts. Our goal is to pragmatically support more rapid scaling and decarbonization impact in the Midwest and other similar regions.

Initial Stages of C&I Electrification in the Midwest

As recently as 2011, Midwest new construction programs incentivized gas-fired hot water reheat systems over electric resistance to reduce utility costs and source energy. At the time this was better for emissions due to high coal-fired and low renewable electricity generation. Our industry wasn't yet able to foretell the impact of locking in fossil-fuels long-term, or the pace of the shift to low carbon electricity.

Over the past decade, research has established a long-term benefit to many electrification scenarios (Nadel 2020; RMI 2019) and greenhouse gas reduction has crystallized as the primary goal of the environmental movement. Corporations have pledged significant carbon reductions and are being valued by it. In parallel, policymakers and regulators have expanded the targets of programs and policies (that were formerly focused on energy or dollars) to include carbon. Minnesota has passed the ECO Act allowing for their large Conservation Improvement Programs to promote fuel switching (MN DOC 2021). The Clean Energy Jobs Act (CEJA) in Illinois not only provided a similar path, but its stakeholder process has led to calls for significant electrification, especially in underserved communities (Illinois, 2021). Other jurisdictions are debating adjustments in their approaches to fuel switching (PSC of WI 2022).

Other developments have made these pivots more feasible to implement. Heat pump-based systems are now available and viable to serve most space and water heating applications in the Midwest, where cold temperatures made this significantly less possible a decade ago. At the same time, programs, codes, and policies need new measures to continue achieving their goals. The stage is set for commercial electrification to grow in the Midwest, though how quickly depends heavily on state and local policy.

The Fastest Path for Midwestern Cold Climates

Preventing global warming from exceeding 1.5°C requires halving carbon emissions by 2030 and then fully decarbonizing by 2050. This leaves little time for inaction in the near-term, and debatably no place for fossil fuels in the long-term. While the long-term reality is technically and economically daunting in the Midwest, it does not have to conflict with the near-term imperative for action. Two uniquely Midwestern pathways can accelerate decarbonization:

Partial electrification, on a path to full decarbonization. Most of the annual heating in Midwestern climates occurs at moderate temperatures, where heat pumps are increasingly more economical and carbon beneficial. Dual-fuel equipment, or in some cases parallel systems that retain legacy fossil fuel equipment, can meet auxiliary heating needs during more extreme conditions. There are leading-edge anecdotes of adequate year-round all-electric system performance even during the polar vortex. With present economics in the Midwest, this can lead to an increase in customer utility costs in retrofit applications. Although this may be amenable to a subset of organizations with aggressive sustainability goals, it is not practical for the mainstream. Dual-fuel solutions reduce the risk to early adopters by addressing cold climate performance, reducing first cost, and providing the option of different fuels to improve utility cost outcomes. They also provide a long-term benefit of dialing in fail-safe pathways to full electrification and its potential capital and operational benefits.

If we ignore the significance of the barriers to full electrification, we may risk slower rates of decarbonization. Many owners will be hesitant to adopt measures that result in significantly greater utility cost and will find ways around those measures. And most dangerous of all, if we install 100% electric systems in applications where they do not perform, we risk giving electrification a bad name that will take years to overcome. Compact fluorescent lighting experienced similar setbacks, markedly delaying their adoption.

Benefiting from other cold-climate markets. Political and technical conditions have prompted leading edge programs in the northeastern U.S. and Europe. Examples include Maine's successful air source heat pump program, NEEP's cold climate heat pump performance standard and database, community-scale thermal utility pilots in Massachusetts and New York, and a range of municipal and state legislation to draw down carbon emissions from buildings. Other markets benefit from accelerated electricity decarbonization due to hydropower and offshore wind. These markets are proving grounds for technology performance and incubators for market development that can de-risk and compress costs for the Midwest as a fast-follower. Embracing connections to and lessons from these markets can accelerate Midwest decarbonization.

Typologies to Electrify

Commercial buildings, including business, educational, and retail uses, comprise 16% of energy-related carbon dioxide emissions in the U.S., about half of the total from the building sector. Over the last 20 years, direct emissions from the residential sector have decreased, while increasing from the commercial sector (Figure 1).

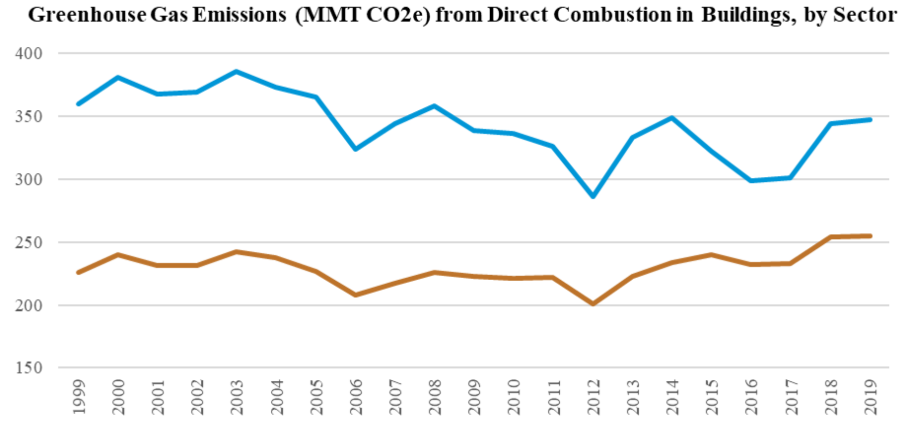

Figure 1: U.S. Emissions from Direct Combustion (U.S. EIA, 2020)

Efficient electrification of heating equipment in commercial buildings is a key strategy to transition the building sector toward a clean, carbon-free future. Electric HVAC, domestic hot water, and cooking systems enable carbon-free buildings as renewable generation transforms the electricity grid. Even in the Midwest, this cleaning of the grid is happening much faster than the lifespan of commercial HVAC equipment.[1] Since buildings exceeding 10,000 ft^2 account for 82% of the total commercial floorspace, targeting these buildings for electrification projects will have an outsized impact on emissions. While the commercial building sector is heterogeneous in nature, we identified a set of common space heating systems as key typologies to demonstrate the viability of electrification for the market. We chose these typologies based on the ability to address heating electrification at scale (Figure 2) and the technical and economic feasibility of near-term implementation in a subset of buildings.

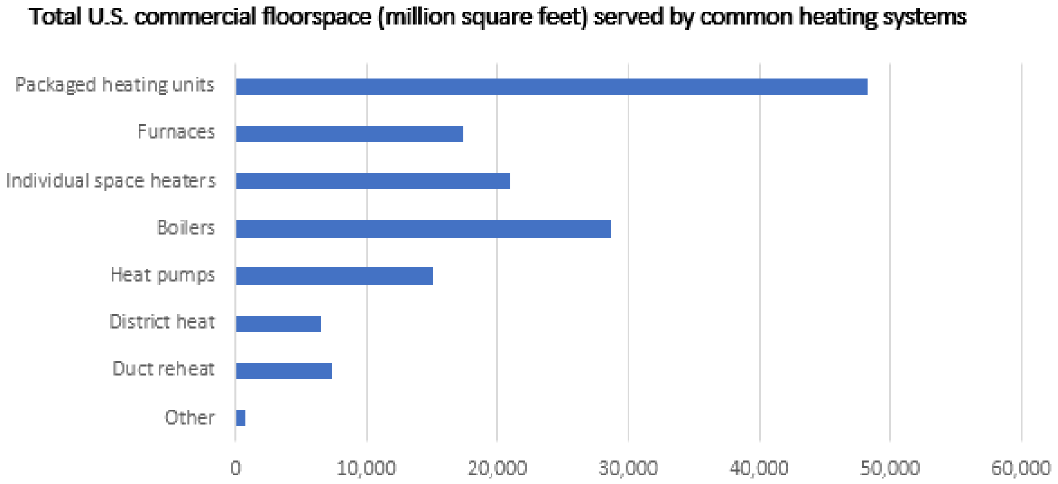

Figure 2: Common commercial building heating systems (US EIA 2018).

Typology 1: Commercial new construction

Implementing fully electric HVAC in commercial new construction is technologically viable in the Midwest today. A key concern around electrification in this region has been adequate heating capacity in extreme cold winter climate conditions without expensive, oversized equipment. In new construction, this challenge is easier to overcome through a holistic design approach that includes high performance building envelopes paired with rigorous mechanical system sizing and efficient heat pump specification.

The first step to achieving an all-electric commercial building is developing a load-efficient design. Project architects should use best practices in energy-efficient design to optimize the thermal envelope, adjusting the exterior window-to-wall ratio and envelope performance specifications (including air infiltration) to minimize heat loss. With appropriate glazing, it is possible to eliminate perimeter heating, reducing capital cost while maintaining occupant comfort. A high-performance envelope can also enable downsizing of mechanical

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[1] In the next 15 years (the lifespan of even short-lived HVAC equipment) 37 coal plans are slated to retire in the Midwest region, and these retirement dates are trending toward sooner rather than later (EPA, 2022).

equipment to smaller capacities, further reducing capital cost. A wide variety of electrification technologies and system configurations can be deployed in new commercial buildings.

Air-source variable refrigerant flow. Over the last five years, manufacturers have developed *cold climate* variable refrigerant flow (VRF) technology that can operate without supplemental heat. These systems use an outdoor unit featuring an inverter driven compressor with vapor injection to maintain capacity and efficient performance for space heating. They are rated to -22°F wet-bulb, but can operate below -30°F. This performance makes VRF the most market-ready air-source heat pump technology for commercial new construction projects.

VRF systems are a great choice for multi-zone buildings, and in general are highly flexible from a design standpoint. Refrigerant loops for these systems can serve terminal units with a wide range of form factors and thermal needs. They allow for simultaneous heating and cooling on the same system, and as a result, heat recovery. VRF systems also require minimal overhead space in contrast to ducted systems. The variable-speed and flow of all system components allows VRF to use minimal energy (near-off) during low-load conditions. Due to its efficient operation in both heating and cooling, VRF can reduce utility cost versus a natural gas system (and in comparison to typical baseline system even save electricity, leading to energy-efficiency program incentives).

While VRF systems have many benefits, they also face several market barriers. The first is capital cost. Simple payback periods are long compared to lower cost conventional natural gas-fired HVAC systems: 8-15 years for offices or K-12 education buildings (FOE 2021). When compared to other higher cost HVAC systems, such as water-source heat pumps or radiant distribution in multifamily buildings, VRF results in immediate or very short payback periods (MECA 2022). VRF systems also require lengthy field-built refrigerant lines. This complicates installation and requires diligent design, construction, and operational maintenance to attain high performance. Care must also be taken to ensure that the climate benefits associated with displacing fossil fuels are not offset by refrigerant leakage, since the most common VRF refrigerant, R-410a, has a global warming potential (GWP) of 2,090. Low-carbon refrigerants will eventually minimize this climate risk. One of the most likely replacements for R-410a is R-32, which is widely used in Europe and has a GWP that is approximately 70% less than R-410a. Further, emerging hybrid system approaches are emerging, such as one using hydronic distribution, limiting refrigerant in the building to less than half of current amounts. Such systems may provide long-term flexibility as climate and safety regulations evolve.

Centralized systems; ground-source or air-to-water heat pumps. For larger commercial buildings (>100,000 ft^2) in the Midwest, heating and cooling equipment is often centralized and boilers are used for heating. All-electric mechanical designs for these new buildings are possible but need to be designed with the specific load balance characteristics of each project. More information about centralized solutions is provided in *See previous typology tables for typical* characteristics.

Typology 5: Retrofit of centralized systems, but the primary strategy is to pursue aggressive *peak* load reduction, not just through efficient envelope and ventilation, but also heat recovery and thermal energy storage. This enables efficient sizing of central heat pumps.

The geology in most Midwest regions enables serving central heat pumps with geothermal heat exchangers, eliminating the cold air temperatures affecting capacity. There are various configurations of this system, including a central water-to-water heat pump or distributed water-to-air heat pumps. The central water-to-water heat pump produces hot water and chilled water for a building, meeting heating and cooling loads efficiently with a hydronic loop. Distributed water-to-air systems use small heat pumps in each zone and are often more cost effective (Kavanaugh 2012). These water-to-air system approaches have been deployed for decades in the region, prior to cold climate air source heat pump technology. The primary challenges to further scaling include significant first cost premium, installation complexity, and space allocation. For new construction projects, integrated architectural, structural, and mechanical design early in project conception can be leveraged to minimize cost impacts.

Recent advancements in air-to-water heat pump technology make this a newly viable central system option in cold climates. An example is Trane's Ascend line. It is available in nominal cooling capacities between 140 – 230 tons. It can deliver 140 °F fluid temperature at 55 °F outdoor air temperature and is capable of heating operation down to 0 °F outdoor air temperature while delivering 100 °F fluid temperature.

Ductless mini-split heat pumps. Ductless mini-split air source heat pumps are a common electrification option for residential applications, and increasingly for smaller commercial buildings. These split systems have much in common with VRF systems, but with less complexity, smaller capacity equipment, and serving fewer zones. They work well for buildings that have enough space to locate many small condensers outdoors. They are also a great solution for electrifying small spaces in larger buildings not easily served by the primary HVAC system.

Mini-split systems may require additional electrical infrastructure as each outdoor unit needs a dedicated 240V circuit with amperages of approximately 30-50A. As overall capacity increases, mini-splits become more cost-intensive than VRF system which have fewer outdoor units. There are no significant market barriers to implementing this simple system today.

Heat pump or dual fuel RTU. The most common system type in commercial buildings is the ubiquitous, highly cost-effective packaged rooftop unit. There are now market ready cold climate, air-source heat pump RTUs available to specify for new construction in the Midwest. For partial electrification, dual fuel RTUs are a viable alternative. This market is worthy of its own typology for retrofit; see the *Typology 3: Rooftop unit retrofit* section. Though that section focuses on retrofit, the technology has even fewer constraints in a new construction application.

Table 1 summarizes the key characteristics of this typology's solutions. Note that similar tables appear for subsequent typologies.

Table 1. Typical characteristics of different solutions for the commercial new construction typology.

	VRF	**Geothermal + HP**	**Mini-split HP**
First cost premium	20-50%	230%	10-20%
Operating cost impact	5-20% increase	30% savings; 16 yr payback	Varies, typically low-cost impact

Heating COP, current equipment	2-2.5	2.5-3.74	Average Seasonal = 2.4 - 3.0 -10F to -20 F = 1.4
Portion electrified	100%	100%	100%
Ancillary changes needed	Increased refrigerant piping and charge.	Significant ground boring for geo-exchange	Specific space allocation for outdoor unit required; application is limited to small buildings or unique commercial spaces
Case study from a cold climate	(MECA 2022)	Ball State Geothermal Pilot Case Study, 2016	Ecotope Ductless Heat Pump Retrofits in Multifamily and Small Commercial Buildings, 2012 NEEP Ductless Mini-split Meta Study, 2016

Typology 2: Multifamily new construction

The new construction multifamily market segment has seen significant growth in the Midwest over the past decade as needs for housing units increase. There is significant literature on electrifying single-family and smaller multifamily buildings; given our focus on commercial-scale buildings this section will address larger multifamily buildings (e.g., greater than 3 stories). There are multiple cost-effective opportunities for electrifying these buildings today.

As discussed in detail in *Typology 1*, while significant attention has been drawn to the ability of heat pump equipment to perform in the coldest hours of the winter, new construction projects can and should leverage a holistic design approach to address this concern. The first step is to optimize the building envelope to reduce the magnitude of heating and cooling loads, ultimately reducing the required size of HVAC equipment.

Air-source VRF systems. Air-source variable refrigerant flow systems are also a viable option for multifamily buildings and have seen significant adoption in the Midwest recently. These systems are highly efficient and, given their performance in cooling as well as heating, have the ability in *some* cases to avoid increased utility bills, relative to fossil-fuel or electric resistance alternatives.

Though these systems seem well poised to address this market segment, some barriers to VRF system adoption remain to be addressed. First, owners are not able to disaggregate the heating and cooling energy use to each living unit, preventing tenants from paying for any share of the heating and cooling directly. Traditionally, this has been handled by rolling that cost into the rent. Second, like other centralized systems, equipment failures in outdoor units can potentially cause all associated indoor units to lose capacity.

In-unit systems. There are also viable HVAC alternatives on the market today for electrifying multifamily buildings with standalone packaged systems per dwelling unit, enabling individual tenant metering. Large through-wall equipment, such as vertical heat pumps (VHPs) are available, inexpensive, and sufficiently meet the space heating and cooling needs of a living unit. The market offers premium versions of these systems, like the Friedrich VRP, which have greatly increase efficiencies. Newer alternatives to traditional through-wall equipment, such as the Ephoca HPAC 2.0 system are available, with smaller wall penetrations. Both technologies feature inverter-driven compressors and manufacturer published specifications indicate heating COP of approximately 1.8-2.2 at 17°F. Designers and contractors should choose either this new generation of VHP or a different system choice to achieve better performance and user experience, if possible.

Central systems. Semi-centralized or centralized systems provide installation and operational efficiency in larger multifamily buildings, making them a common heating system configuration. In new construction, the most cost-effective solution in the Midwest is unitary water-source heat pumps within each dwelling unit that are connected to a central condenser loop, leveraging load diversity and the fan and compressor heat from heat pumps to reduce load on a central heat generation source. Owners or tenants can be metered separately for in-unit heating electricity use. In more typical existing applications, the central condenser loop is tempered with a natural gas boiler. The system can be fully electrified using a geothermal heat exchanger or emerging large air-to-water heat pumps serving the building's central plant, see *Typology 1: Commercial new construction* for more detail.

Typology 3: Rooftop unit retrofit

Packaged rooftop units (RTU) are common on commercial buildings throughout the United States because of their low upfront cost, reliability and mature service and distribution network. Packaged RTUs serve approximately 34% of commercial buildings in the United States, serving approximately 45 billion square feet (US EIA 2012). They are particularly ubiquitous in the office, retail, warehouse, and education segments. Existing packaged RTUs overwhelmingly use natural gas for heating. Replacing this gas usage is a major step in electrifying commercial buildings. When replacing existing RTUs, owners are generally focused on low-cost, one-for-one replacement-on-burnout.

There are two one-for-one replacement options that can work today in the Midwest: heat pump only or dual fuel units. HP RTUs utilize a heat pump for cooling and all heating, potentially with electric resistance backup. Efficiency decreases with decreasing ambient temperatures. For example, the COP of Daikin's DP14DM RTU is 3.58 at 47°F, but drops to 2.42 at 17°F, and 1.31 at -10°F. HP RTUs are available in capacities spanning the range of existing RTUs. Dual fuel RTUs include a heat pump for cooling and first-stage heating, for use at moderate ambient temperatures. A natural gas fired heat exchanger takes over at low ambient conditions. Dual-fuel units are currently available in 2 to 5 ton options across multiple manufacturers, and a couple of manufacturers currently have 7.5 and 10 ton options.

Slipstream modeled these two options across three sectors: office, retail, and education. For energy savings, we compared the dual fuel and HP RTUs to both an existing and code-compliant gas-fired baseline to represent both the owner and program perspectives, respectively.[2] We also interviewed manufacturers and summarized barriers. Table 2 shows the results of this:

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[2] In this analysis, the Dual Fuel and Heat Pump RTUs were assumed to have cooling efficiency of SEER 15.2 and 18.5, respectively. The existing RTU had a constant speed fan, while all replacement RTUs were assumed to have variable speed fans. The dual fuel RTU assumed a 35°F crossover point.

Table 2. Typical characteristics of electrified RTU solutions.

	Dual Fuel RTU	**Heat Pump RTU**
First cost premium	20% premium	20-50% premium
Operating cost impact	Existing: 20-30% decrease Code-Compliant: 15-20% increase	Existing: 5-20% decrease Code-Compliant: 35-40% increase
Heating COP, current equipment	8.0-8.5 HSPF	3.2-3.6 COP
Portion electrified	~50%	100%
Ancillary changes needed	Structural or electrical changes unlikely	Structural changes unlikely, electrical upgrades potentially
Case study from a cold climate	None[3]	None[3]

Dual fuel RTUs decrease electricity consumption versus the existing system scenario, but increase electricity consumption versus a code-compliant replacement option, driven by the switch from constant to variable speed fans. HP RTUs increase electricity consumption versus the existing RTUs and increase consumption even further when compared to a code-compliant gas replacement. In this case fan savings are not sufficient to offset the electrification of heating. With respect to gas, the dual fuel RTUs cut natural gas consumption approximately in half, while the HP RTU eliminates natural gas consumption completely. The dual fuel RTU does offer the additional capability of using natural gas at design heating temperatures to minimize or completely offset peak demand. Though technically feasible today, there are several market barriers to widespread heat pump retrofit of RTUs today.

Capital Cost: There is a significant cost premium for HP RTUs today. Daikin manufactures a cold-climate heat pump RTU (Rebel; not a dual-fuel unit) that has a 50% cost premium over traditional RTUs. Additional costs are also incurred because these manufacturers do not recommend a one-to-one replacement. In cold climates, the heating capacity is larger than the cooling capacity, requiring a larger heat pump RTU (both in cooling capacity and physical size) than the gas-fired RTU it is replacing. The increased footprint often requires an engineer to review sizing. As for dual-fuel, Trane quoted a 20% premium for their products that are dual fuel as opposed to standard RTUs. Sizing would be less of an issue, or possibly not an issue at all, for dual-fuel systems.

Utility Cost: The increase in building owners'/operators' utility costs is a major barrier to HP RTU deployment at scale. Preliminary modeling for commercial buildings in climate zone 5 shows a net increase in utility cost for HP-only RTUs, driven primarily by the utility rates and the HP heating efficiency. For the utility cost to remain neutral, there would need to be a 35% decrease in electricity rates ($0.158 to $0.103/kWh), a 40% increase in natural gas prices ($0.865 to $1.211/therm), and a 25% increase in heating seasonal efficiency (COP of 1.8 to 2.25). Using dual-fuel RTUs would reduce each of these impacts approximately in half.

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[3] The authors are aware of field evaluations of heat pump RTUs in moderate to hot climates, but none in cold climates.

Availability: RTUs are most frequently replaced when they fail. As a result, a replacement is needed as soon as possible. It is difficult to meet this need with heat pump RTUs because typically they are not stocked or readily available due to low demand.

Immature market: Because the current market for HP RTUs is small, there are limited incentives for manufacturers to develop tools to support them (such as tools that predict their performance). And without supporting data, potential customers do not have the information they need to choose a HP RTU over an alternative.

Typology 4: Retrofit of in-unit systems for multifamily and lodging

Larger existing multifamily and lodging buildings range in age and size, making this a challenging segment to electrify using a one-size-fits-all approach. Retrofit projects have less flexibility than new construction and so warrant their own typology. But multiple technologies and strategies exist to electrify most of these buildings. There is value in strongly considering envelope improvements first, to enable better, more cost-effective performance from your electrified system, as envelope improvements – particularly air sealing – tend to yield cost-effective outcomes. Options include air sealing, window replacement or attachment, and even over-cladding prior to electrification. In some instances, these measures may also be warranted to ensure or even improve thermal comfort for occupants, especially considering the slightly cooler delivery temperatures from electric heating equipment.

After addressing any potential improvements to the envelope and load reduction, designers should consider if a full system switch (to something like VRF) is warranted or if the existing system type can be retained while electrifying specific pieces of equipment (often the most cost-effective path). Both are possible options in many cases. We describe the necessary decisions below for a few different scenarios.

Replacing unitary gas-fired equipment. One challenge specific to retrofitting in-unit gas furnaces to heat pumps can be the existing electrical infrastructure. Projects need to evaluate the in-unit electrical service and panel capacity to determine if a heat pump can be supported. If the in-unit electrical panels cannot support a heat pump, then a system switch may (e.g., VRF or centralized system) may be more cost competitive.

Designers should also consider what level of backup or supplemental heat is required. Ideally backup heat is eliminated as it is generally inefficient electric resistance, but it is important to avoid creating significant comfort issues. For systems which require significant supplemental heat, a dual fuel approach may be considered (e.g., a gas furnace plus heat pump). However, space constraints, particularly in large multifamily, may make this infeasible.

If individual gas meters are eliminated in each unit, there is large additional savings for the tenants. In many larger multifamily buildings, the fixed meter charges are a much larger share of utility costs than in other residential contexts (due to low gas usage per meter).

Whole-system replacement. There are also viable electrified solutions for whole-system replacement. Basic one-for-one equipment replacement alone may run into too many barriers on some projects: capacity, electrical infrastructure, cooling or heating delivery changes, desired efficiency, etc. Alternatively, owners may opt for a new system for other reasons. One system that is particularly suited to multifamily retrofits is VRF, due to the flexibility in routing components using small refrigerant lines (or hydronic distribution in the case of hybrid VRF). VRF becomes an even more attractive option for historic buildings or other unique building retrofits where running larger ductwork or piping is prohibitive due to atheistic or other design limitations (concrete walls, etc.). There can be some challenges with tenant billing, as it is not possible to meter the heating and cooling electricity by living unit. Owners and landlords have compensated for this by adjusting rent or fees. These types of replacements may also be a solution for older buildings with steam heat or high temperature hot water distribution.

See previous typology tables for typical characteristics.

Typology 5: Retrofit of centralized systems

One typology that looks quite different from others is central plant electrification. This broad category includes a variety of large and complex centralized systems, comprised of a variety of components as shown in Table 3. It is differentiated by being much greater in capacity, infrastructure, and complexity than other replacements.

Table 3. Common existing centralized system typologies.

Distribution Systems	**Heating Source**	**Cooling Source**
Central ventilation AHU, plus:	Gas-fired steam boiler	CHW loops from:
-Perimeter steam radiators	Gas-fired HHW boiler	-Chiller + cooling tower
-Hot water (radiators, fancoils, induction)	District steam	-District cooling
-Zonal WSHP/VRF on CW loop	Electric (esp. reheat)	Packaged Air Handlers
Centralized VAV	Cogeneration	CW loop + cooling tower
Floor-level AHU on HHW/CHW/CW loops		Absorption chillers

Color key:
Multi-family
Commercial
MF and Comm

For retrofits or replacements to these systems, unique technical barriers include distribution system compatibility with heat pumps and space and economic constraints on heat generation capacity. Current solutions are bespoke for a given building and are almost never handled with simple one-for-one replacement of gas-fired equipment with heat pumps. They instead require a custom, long-term strategic decarbonization plan that transitions a building over time. This plan can be sufficiently long-term to be tied to triggers that will occur in long-term asset management and capital improvement, rather than isolated retrofit interventions. This process is called resource-efficient electrification, an approach illustrated by examples from NYSERDA's Empire building Challenge as described in Table 4 (Bridgeland, 2022). Such comprehensive electrification retrofits are comprised of the following steps:

Reduce. It may not be physically or economically possible to simply replace a large central boiler or district steam supply with the same peak heat generation capacity via a central heat pump. Bridging the gap between those two should start with efforts to reduce peak loads. Load reduction in buildings like these can include: a variety of HVAC retro-commissioning and automation strategies; ventilation controls and innovative air cleaning; envelope air sealing; and window attachments or even over-cladding. Envelope improvement would likely be tied to façade maintenance, market repositioning, tenant demands or a comprehensive deep retrofit.

Reconfigure. Building distribution systems with steam or high-temperature hot water (180°F) may not be compatible with the more moderate heating output temperatures (135°F) required for both heat pumps and heat recovery. Some buildings may require significant re-piping and replacement of terminal units, creating entirely new hydronic loops or repurposing condenser loops. Because re-piping could be invasive and expensive, this would likely require creativity and bespoke solutions. The timeline would be concurrent with tenant turnover (another trigger). Variable Air Volume (VAV) systems have opportunities to decouple ventilation from space conditioning, shift to hydronic terminal heating units, or add air-to-air heat recovery.

Recover. Heat recovery technologies can add significantly to heat capacity, further reducing the need for electric heating. Some of this heat is very typically discarded from midwestern buildings today year-round, via cooling towers or economizer cycles (which may need to be shut off), or refrigeration or data center cooling. Heat recovery chillers, VRF fit-outs and hydronic condenser loops inherently enable easier heat recovery. Other recovery strategies include exhaust air heat exchangers, distributed energy recovery ventilators, building and municipal wastewater heat recovery, and heat pump-driven energy recovery.

Store. The usefulness of heat recovery increases if heat can be stored on diurnal cycles, allowing commercial buildings to heat themselves for more of the winter and leveling out space- or water-heating peaks to reduce needed heat pump capacities. Heat can be stored passively in the thermal mass of the building, or dedicated thermal storage can be integrated into thermal networks described above – in water, ice (counterintuitively, also useful for heating), and other phase change materials. Such solutions can have better economics and longevity than batteries.

Replace. With peak heating loads limited by the four steps above it becomes much more feasible to replace some or all fossil fuel heat inputs with heat pumps. In a thermal network, this can include a range of heat inputs such as large central ASHPs, distributed ASHPs, compressor-driven heat recovery, heat sharing in a multi-building network, and a range of water-source and ground-source heat sources. Low-efficiency electric resistance today would be ideally limited to specialty high-quality heat needs. It may be helpful to select and phase-in technologies based on temperature-bin analysis, where heat pump technologies today can meet a large majority of loads and infrequent peak design conditions are solved separately or later. Today's heat pumps do not generate steam, meaning steam systems will need to consider conversions from steam to hot water distribution, which is already a common measure for improving efficiency.[4]

In most cases, because of the comprehensive and potentially invasive nature of decarbonizing these buildings, it may be infeasible to execute an entire project in one move. This is not reason for inaction, but rather highlights the immediate importance of conducting a strategic decarbonization assessment to start long-term decarbonization planning now. Then, as triggers occur in the lifecycle of the building – tenant turnover, sale, purchase, repositioning,

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[4] Some steam system owners are exploring decarbonization pathways involving combinations of electric resistance boilers, condensate recovery, heat pump preheating of feedwater or expectations of increased access to biofuels, hydrogen, or renewable natural gas for future boilers

major equipment replacement, building performance compliance – investments can be made which fall on the path to decarbonization and account for risk and future-readiness.

Table 4. Case studies of resource efficient electrification in the Northeast (NYSERDA, 2022).

Omni New York, Whitney Young Manor (affordable multi-family)	Exterior Insulating Façade System, new windows, new roof. New centralized heat pump system and energy recovery ventilation.
L+M, The Heritage (mixed multi-family)	Exterior Insulating Façade System, new windows. New packaged terminal heat pumps.
Empire State Building (office)	District steam optimization through load reduction and heat recovery. Partial hot water conversion. Air and water source heat pumps (with condenser loop) with heat recovery.
Hudson Square Properties, 345 Hudson (office)	Floor-by-floor replacement of terminal units with water source heat pumps. Dedicated outside air system. Use of fire protection water tanks for thermal storage. Connection to adjacent building.

Cross-cutting Solutions

In order to bring these systems to scale in the market, the strategies described below should be pursued to overcome corresponding barriers.

Technology transfer to designers, operators, and the supply chain. Designers and operators can most efficiently deploy and operate what they have used in previous buildings and projects. Most architecture and engineering firms in the Midwest have not designed an efficient all-electric building. Distributors and manufacturer representatives, who stand to gain from selling more expensive equipment, do not understand the value proposition of this heat pumps.

Education on electrification is the obvious first solution to this barrier; educational efforts will need to be broad, addressing the different types of stakeholders listed above. But more targeted approaches are needed as well. Case studies of electrified buildings in the Midwest in different segments and configurations will help. They will need to share their accomplishment, lessons learned, and if possible, the specifications that were used. Distributors and manufacturer representatives will need calculators allowing them to understand the value proposition of the equipment they're selling in different configurations. The manufacturers themselves are beginning to develop these, but this is also an appropriate target for decarbonization and electrification programs run by utilities and other organizations.

Decision-maker awareness. Beyond the key professionals like designers and operators, the broader market (especially decision-makers like building owners and public officials) needs to view electric heat as a positive solution and not a more expensive option being forced upon them by policymakers. The types of marketing and initiatives that have led to positive perception of green buildings can be replicated with the notion of electric heating. This may be most effective if led by someone other than the electric utility because of perceived conflicts.

More certainty in performance. There is still significant concern about the performance of this equipment at low design temperatures; many populations have design temperatures of -

15°F or lower. Equipment needs to be trusted to meet capacity at this temperature and operate with reasonable efficiency down to near this temperature. For many projects (e.g., public buildings), finding three products that can meet a specification for competitive bid is a barrier.

More testing and study of product ratings is needed to create trust in the current rating systems. Cold climate air source heat pumps (NEEP, 2021) and VRF (Ridgeline Analytics, 2023) are currently both under study. Other equipment types, like RTUs and heat pump chillers, should have similar studies completed. But testing alone is not enough; additional market development is needed to encourage competition within different product categories. A national manufacturer challenge akin to the current residential cold climate heat pump (reference) would be beneficial.

Shifting the economic paradigm. The green building movement has historically leveraged the fact that many sustainable choices also save operating costs, with energy bill savings justifying incremental capital investments. But particularly in the early days of Midwestern electrification, energy bill or capital cost savings may be hard to realize and may only ever provide small benefit relative to other investments. Our industry may need to illuminate a shift in the economic paradigm for electrification specifically. For a goal of widespread, mainstream electrification the magnitude of this barrier should not be understated. In observing the projects discussed in this paper, we have identified possible strategies:

- Ensure an apples-to-apples comparison of capital costs, e.g., high-end heat pumps versus high-end fossil-fueled equipment.
- Value non-energy benefits such as maintenance, health, resilience, and brand.
- Decarbonize over time, particularly where electrification requires enabling work or where a partial electrification strategy is preferred.
- Consider fuel cost stability over the lifetime of the equipment; electricity tends to be more stable (Gruenwald,2021).
- Take a multi-decade lifecycle analysis approach. System types installed today may still be in service in 2050 when climate action demands a different energy paradigm. This transition may dictate new economics and remediation of outdated systems.
- Include the economics of current or prospective policy carrots or sticks such as tax credits or building performance standard penalties. Municipalities are beginning to enact significant financial impacts (Nadel, June 2020).
- Consider present and future environmental, social, and governance commitments.
- Ensure that gas distribution, maintenance, and especially gas meter charges are included in the analysis. In full-electrification scenarios, these can result in significant savings.
- Include utility infrastructure in the project design and analysis boundary. There is a role for building professionals to play in planning a rational energy transition at a neighborhood, city or even utility scale. Consider cost of gas connections to the building, or even neighborhood-scale distribution. Consider possible benefits to the electric utility

Regulatory and rate-making improvements. This paper focuses primarily on actions in the buildings industry, so a discussion of utility regulatory barriers and solutions is for another time. But the buildings industry should recognize that solutions are likely on the way in the form of 1) regulation of energy programs that allows for financially incentivizing electrification and 2) adjustments in ratemaking. These are warranted to reflect the value of decarbonization to the community and the grid, and so are being worked on in a number of jurisdictions. These changes will hopefully lead to more favorable economics for those in the buildings industry. Building professionals should advise and advocate in making these transitions.

Electrical infrastructure, front of the meter**.** Include electric utilities in the strategic decarbonization assessment planning. Identify and address any service upgrade or other distribution system barriers your project may mitigate. Capture synergies with planning and investment in transmission and distribution, renewable energy, storage, or vehicle charging. These can all lead to overall economic benefits. At the same time, electric utility distribution is a potential feasibility barrier in some locations as some commercial buildings may require electrical service upgrades to fully electrify. Owners and operators should be discussing these upgrades with utilities in advance.

Conclusion

In summary, building projects in the Midwest have a few clear paths to electrify:

- **Commercial new construction** is a priority segment to electrify through holistic design to lower building loads, and a variety of all-electric HVAC system options.
- **Multifamily new construction** is also positioned for electrification today when coupled with a robust envelope; options exist for centralized (primarily WSHPs) and distributed (VRF or VHPs) approaches.
- **Retrofit of rooftop units**. The ubiquity of RTUs makes them a critical electrification target, but dual-fuel approaches and program support are needed for good economics.
- **Retrofit of in-unit housing** is possible via VRF or VHP equipment, but it can be challenging; envelope or electrical infrastructure upgrades may be needed first.
- **Retrofit of centralized systems** is not possible with one-time equipment replacement alone; a Reduce → Reconfigure → Recover → Store →Replace progression is needed.

References

Bridgeland, Brett. 2022. “Decarbonizing Tall Buildings with a New York State of Mind.” https://rmi.org/decarbonizing-tall-buildings-with-a-new-york-state-of-mind/

Environmental Protection Agency. Announced Power Plant Retirement Map. Accessed March 2022.https://epa.maps.arcgis.com/home/webmap

Focus on Energy (FOE). 2021. Cold Climate Variable Refrigerant Flow Program Study. Prepared by Slipstream and Minnesota Center for Energy and Environment.

Gona, Ashita and Mike Henchen. 2021. “US Can’t Meet Climate Goals While Spending Billions on Gas Infrastructure.” RMI. https://rmi.org/us-cant-meet-climate-goals-while-spending-billions-on-gas-infrastructure/

Gruenwald, Talor. 2021. “Reality Check: The Myth of Stable and Affordable Natural Gas Prices.” RMI. https://rmi.org/the-myth-of-stable-and-affordable-natural-gas-prices/

Im, Piljae et al. Case Study for ARRA-Funded Ground-Source Heat Pump Demonstration at Ball State University. October 2016. https://info.ornl.gov/sites/publications/Files/Pub71170.pdf

Kavanaugh, S., J. Kavanaugh. Long-Term Commercial GSHP Performance: Part 1: Project Overview and Loop Circuit Types. ASHRAE Journal. June 2012.

Larson, Ben et al. Ductless Heat Pump Retrofits in Multifamily and Small Commercial Buildings. 2011. https://ecotope.com/ecotope-publications-database/

Michigan Electric Cooperative Association (MECA). 2022. Air Source Variable Refrigerant Flow Field Study. Prepared by Slipstream.

Minnesota Department of Commerce (MN DOC). Governor Walz celebrates landmark ECO Act. July 27, 2021. Governor Walz celebrates landmark ECO Act (mn.gov)

Nadel, S. and A. Hinge. Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals. June 2020. https://www.aceee.org/sites/default/files/pdfs/buildings_standards_6.22.2020_0.pdf

Nadel, S. and C. Perry. Electrifying Heating in Existing Commercial Buildings. October 2020.

Northeast Energy Efficiency Partnerships, Inc (NEEP). “Request for Proposals: Heat Pump Rating Representativeness Projects.” https://neep.org/sites/default/files/media-files/hp_representativeness_research_project-rfp_7.7.21.pdf . 2021.

NYSERDA. 2022. “Empire Building Challenge Projects.” https://www.nyserda.ny.gov/All-Programs/Empire-Building-Challenge/Empire-Building-Challenge-Projects

Rocky Mountain Institute (RMI). The Impact of Fossil Fuels in Buildings. 2019

State of Illinois. Gov. Pritzker Signs Transformative Legislation Establishing Illinois as a National Leader on Climate Action. State of Illinois. September 15, 2021. https://www.illinois.gov/news/press-release.23893.html

State of Wisconsin PSC. Docket 5-FE-104, Quadrennial Planning Process IV. Accessed March 2022. https://apps.psc.wi.gov/APPS/dockets/content/detail.aspx?id=5&case=FE&num=104

U.S. Energy Information Administration, CBECS 2012, Table B40 and B41.

U.S. Energy Information Administration, CBECS 2018.