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Guidance Document on Space Heating Electrification for Large Commercial Buildings with Boilers

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Disclaimer

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List of Acronyms

A2W	air-to-water
AC	air-conditioning
AHU	air-handling unit
ASHP	air-source heat pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTU	British thermal unit
CBECS	Commercial Buildings Energy Consumption Survey
CBI	Commercial Building Integration
CCH	Colorado Coalition for the Homeless
CCHP	cold-climate heat pump
CHFA	Colorado Housing and Finance Authority
ComEd	Commonwealth Edison
COP	coefficient of performance
DOAS	dedicated outdoor air system
DOE	Department of Energy
DX	direct expansion
EIA	Energy Information Administration
ERV	energy recovery ventilator
EUI	energy use intensity
GEB	grid-interactive efficient building
GHG	greenhouse gas
GSHP	ground-source heat pump
GWP	global warming potential
HP	heat pump

HVAC	heating, ventilation, and air-conditioning
kWh	kilowatt-hour
M&V	measurement and verification
NYSERDA	New York State Energy Research and Development Authority
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
RD&D	research, development, and demonstration
RTU	rooftop unit
SMUD	Sacramento Municipal Utility District
VAV	variable air volume
VRF	variable refrigerant flow
VTHP	vertical terminal heat pump

Executive Summary

Background

Building decarbonization is an increasingly important topic for owners of large commercial and multifamily buildings due to the increased city, state, and federal government regulations surrounding building greenhouse gas (GHG) emissions as well as GHG emissions reduction goals of the building tenants. Space heating, especially in large commercial buildings, is a key component to building decarbonization. Most large buildings and many multifamily residences use natural gas or steam boilers to produce hot water to meet space heating demand and tenant comfort requirements. This guidance document focuses mainly on electrification strategies for fossil fuel boilers for existing buildings, which have greater challenges than new-construction applications. Although the topic of commercial building electrification has seen increased interest in recent years, the majority of projects and case studies focus on new construction rather than retrofitting existing systems, which make up the vast majority of commercial buildings.

Goal of this Guidance Document

With support from the U.S. Department of Energy's (DOE's) Commercial Buildings Integration (CBI) program, Guidehouse Inc. (Guidehouse) prepared this guidance document to summarize key considerations for those with existing buildings with hot water or steam boilers who are looking to retrofit their space heating systems to one or more electric heat pump technologies, such as air-to-water (A2W) hydronic heat pumps, variable refrigerant flow (VRF) heat pumps, heat recovery chillers, or other strategies. This guidance document was developed using information gathered from literature reviews, stakeholder interviews with system designers and other industry experts, and case studies. The guidance document is meant to help building owners, contractors, and other stakeholders involved with heating, ventilation, and air-conditioning (HVAC) design and purchasing decisions, especially for large, existing commercial and multifamily buildings. The document covers the barriers of implementation, the design/replacement process, the involved stakeholders, potential infrastructure upgrade needs, and feasibility challenges. The ultimate goal of this document is to provide foundational information for building owners to begin the process of analyzing the feasibility of a potential electrification retrofit with their facilities and design teams.

Motivations for Electrification

During our research, stakeholders cited several motivations for why building owners would do an electric retrofit of a natural gas hot water system, including life cycle cost and energy savings, electrification outlook, regulations, incentives and rebates, sustainability goals/commitments, occupant comfort, and maintenance savings. Achieving the lowest life cycle cost is the most prominent driver for electrification. In addition, local regulations to electrify and reduce emissions are driving building owners to update their systems or conduct feasibility studies to understand what it would take to meet these regulations.

Electric Space Heating Technologies to Replace Fuel-Fired Boilers

Steam or hot water boilers used for space and water heating in larger commercial and multifamily buildings use natural gas, fuel oil, or both, with the primary fuel today being natural gas (90% of commercial boiler space heating energy).[1] Each large existing building is uniquely designed and presents system designers with various site-specific design constraints that require creative and unique solutions. Manufacturers have developed a wide range of electric heating technologies and system designs to integrate with existing infrastructure and/or replace existing infrastructure with entirely new designs to meet the unique needs of each building.

Multiple electric space heating technologies can be considered to replace fuel-fired boilers either as an individual technology or in coordination with other electric technologies, including the following:

- **A2W Heat Pumps**: A2W heat pumps use a vapor compression cycle to generate hot water and distribute it throughout the building to radiators, variable air volume (VAV) boxes, and other heat exchangers for space heating.
- **Heat Recovery Chillers**: Heat recovery chillers recover the heat that is removed from the chilled liquid and simultaneously produce cooling and space heating.
- **VRF Systems**: VRF systems distribute refrigerant to conditioning units in individual zones throughout the building to provide heating and/or cooling.
- **Electric Boilers**: Electric boilers use electric resistance heating to generate hot water and distribute the water throughout the building, similar to a fuel-fired boiler.
- **Packaged Terminal Heat Pumps (PTHPs)**: PTHPs provide heating and cooling to individual rooms without a central distribution network, as they are installed directly through the walls of the building.

Other design strategies include ground-source heat pumps (GSHPs), which use a ground loop as the heat source and sink for the heat pump and can improve efficiency over air-source systems, as well as cascade heat pump designs, which combine multiple heat pump technologies to meet the building's heating and cooling loads. For example, A2W heat pumps provide heat input to a centralized water loop that connects with floor-by-floor or in-unit water-source heat pumps in a cascade heat pump design.

Key Stakeholders and Project Life Cycle

A variety of stakeholders can be involved in any building retrofit process, including the following:

- **Building owners** are ultimately in charge of the decision-making process.
- **Engineering firms, design consultants, and architects** determine the best HVAC system designs, perform energy studies, and complete measurement and verification (M&V) studies.
- **Contractors** provide the installation of the new technologies.

[1] U.S. Energy Information Administration (EIA). 2012. 2012 CBECS Survey Data. www.eia.gov/consumption/commercial/data/2012/.

- **Utilities and state and local governments** provide indirect contributions through incentives, grants, rebates, tax credits, etc.

Retrofit projects almost always begin with a feasibility assessment carried out by the engineering firm or design consultant. These assessments typically take 2–3 months and are necessary to understand the layout of the building infrastructure. This phase is followed by a design phase in which the engineers determine the best possible solution for the building, which typically lasts an additional 3–5 months. The design phase is followed by the construction phase, which can last anywhere from 3 months to over 1 year to complete, but this varies greatly from building to building. Figure ES-1 shows the project timeline and describes some of the involved stakeholders.

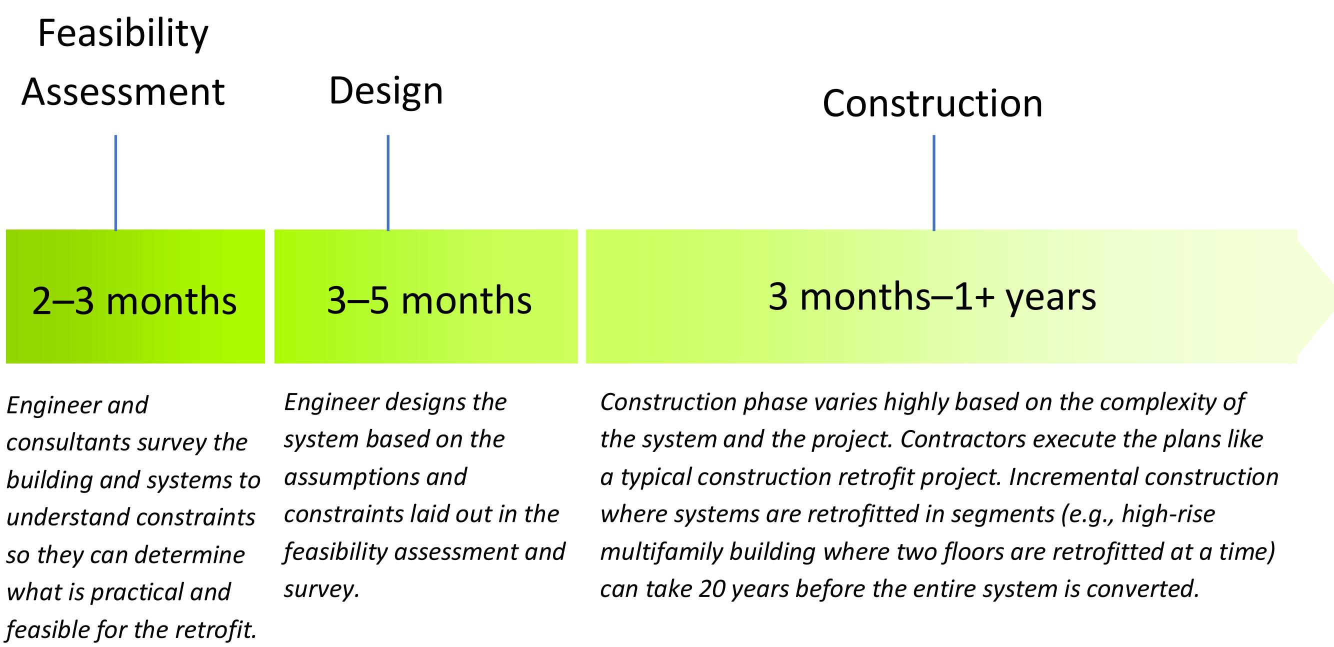

Figure ES-1: Retrofit project life cycle

Project Barriers and Challenges

There are several challenges and barriers that building owners and designers should consider when starting a retrofit project or feasibility assessment. Based on conversations with several stakeholders, the team developed a list of key strategies that could help accelerate the adoption of electrifying boiler systems as well as the most common barriers and constraints that stakeholders have seen or anticipate. Some of the key considerations to analyze are building space constraints, infrastructure impacts, capital and cost constraints, project timeline considerations, and payback considerations. The key challenges include first cost, operating cost, space constraints, water temperature requirements, heat demand, split incentive, and workforce. Some of the key strategies and considerations that have been successful when retrofitting a building's hot water system are described in Table ES-1.

Table ES-1: Key Strategies for Electrification Projects

Strategy	Description
Lowering building water temperature	Temperatures in the range of 120–150°F can often provide sufficient heating for a building instead of the traditional 180°F, according to design consultants. Incrementally lower hot water temperatures and test building operation and comfort to see what hot water temperature is actually required.
Utilizing boilers for supplemental heating	Make the boiler a supplemental heating source rather than the primary source. The supplemental heating system would only be used during outages and high peak periods, which could lower the operating hours and save operating costs for the electrical systems.
Incremental retrofits	Upgrading systems gradually over time can help spread the cost of an electrification project over a more manageable time frame.
Reducing the building load	Implementing efficiency upgrades first can contribute to lowering the building heating load and will require less heating capacity. This is helpful to reduce the size of both the required electric heating technology and the upgraded electrical panel.

Summary and Conclusions

The switch from fossil fuel-fired boilers to electric heating technologies comes with challenges, but a number of strategies and opportunities are available to help with project evaluation and implementation. Table ES-2 describes the challenges and potential strategies to address and mitigate the barriers for adopting all-electric solutions. Building owners are increasingly interested in decarbonizing their building portfolios, and the number of electrification projects for large, existing commercial buildings will increase in future years. Where challenges exist today, manufacturers and system designers will continue to innovate and find cost-effective solutions to achieve the decarbonization goals. Despite these challenges, building owners who make the switch from a fossil fuel-dependent boiler system to high-efficiency heat pumps and other electric technologies will have lasting emissions benefits for their facilities, tenants, and communities as the electricity supply to the buildings continues to decarbonize.

Table ES-2: Challenges and Strategies for Boiler Retrofits

Challenge	Strategy
Most hydronic heat pumps are unable to produce hot water in the necessary temperature range of ~ 180°F without auxiliary heating systems.	Some existing hydronic distribution networks can be adapted to provide equivalent heating comfort with **lower-temperature water** (120–150°F).
Large buildings with large peak heat demands require high-capacity heat pumps, which are capital intensive.	**Building efficiency measures** such as insulation upgrades and heat recovery can reduce the building heating load, reducing the capacity and cost of the installed heat pumps.
The capital cost to install an electric heat pump is likely larger than that of a fuel-fired boiler.	Heat pumps operate much more efficiently than fuel-fired boilers and can allow for **operating cost savings** in many regions of the country.

Challenge	Strategy
The first cost of a gas-to-electric retrofit can be large and may disincentive building owners from exploring project options.	Spreading out the decarbonization project over multiple stages as an **incremental retrofit project** can lower the initial cost burden and disruption to existing tenants while also incorporating greater energy efficiency to make an easier transition to electrification.

To showcase how electrification is feasible for large existing buildings, this document also contains a series of case studies for completed and under-development projects across the United States. The authors, DOE, and Better Building partners are interested in profiling additional successful electrification projects and encourage those involved in the design and construction of these projects to reach out to the authors or the DOE Better Buildings program to discuss the opportunity further. If you are interested in working with DOE on this effort, please contact BetterBuildings@ee.doe.gov.

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1 Introduction

1.1 Background

Building decarbonization is an increasingly important topic for building owners to consider due to the increased state and federal government regulations surrounding building emissions and the industry shift to more sustainable emissions goals. Building decarbonization involves several strategies, including energy efficiency, renewable energy sources, and electrification of end-use appliances.[2] Upgrading the building envelope, HVAC systems, water heating, refrigeration, major plug loads, and other equipment decreases thermal and electrical demands within the building and supports overall decarbonization efforts. Adding on-site renewable energy resources to generate clean electricity also reduces dependence on fossil fuels and offsets the need for utility-provided electricity, which often has higher indirect emissions. Appliance electrification is another major strategy for building decarbonization and refers to replacing on-site fossil fuel-consuming equipment with electric equipment and appliances. High-efficiency heat pump (HP) technologies available today present building owners and operators with a diverse set of options for electrification of space and water heating loads. This guidance document focuses mainly on the electrification of fossil fuel boilers for existing buildings, which have greater challenges than new-construction applications.

Many state and city governments have aggressive climate goals that aim to reduce on-site fossil fuel consumption. Similarly, numerous corporations and organizations have also set sustainability and decarbonization goals for their operations, including the energy consumption associated with their buildings. Programs such as DOE's Better Climate Challenge support organizations to set ambitious, portfolio-wide GHG emissions reduction goals, including portfolio-wide GHG emissions reduction by at least 50% within 10 years.[3] As more state and local government policies and organizational sustainability initiatives are introduced, more commercial buildings will explore different decarbonization strategies.

Space heating, especially in large commercial buildings, is a key component to building electrification. Most large buildings and many multifamily residences use natural gas or steam boilers to produce hot water to meet space heating demand and tenant comfort requirements. According to the Energy Information Administration's (EIA's) 2012 Commercial Buildings Energy Consumption Survey (CBECS), space heating makes up approximately 25% of all commercial building energy consumption annually, about 1,755 trillion British thermal units (BTU) (Figure 1).[4] Of the 1,755 trillion BTU consumed for space heating, only 5% is from electrical equipment, and the remaining 95% is from fossil fuel-using equipment, mainly natural gas. In order to decarbonize many large commercial buildings, building owners and system designers must evaluate all-electric alternatives to natural gas and other fossil fuel boilers.

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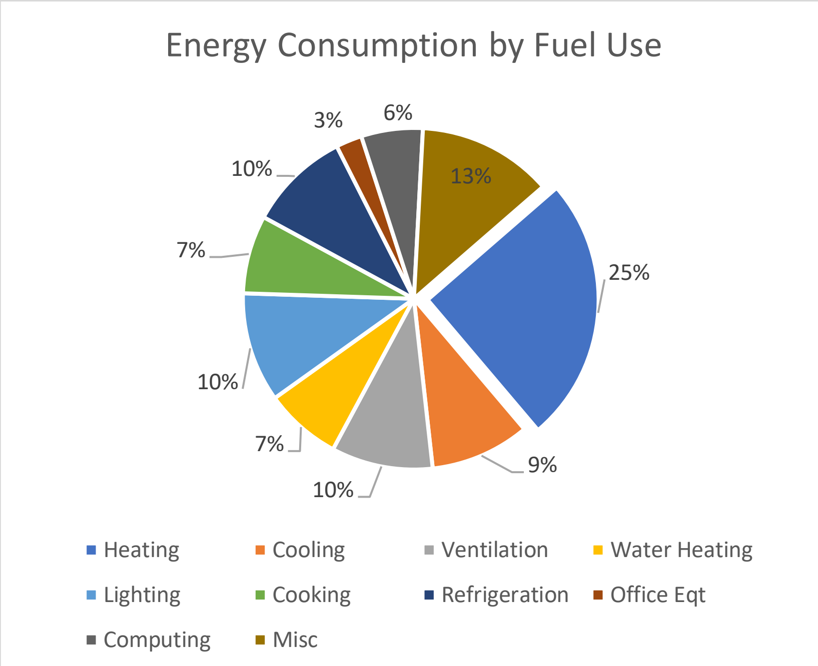
[2] This report focuses on technology, design, and implementation strategies for space heating electrification. Low-carbon fuels such as biomass, renewable natural gas, and hydrogen are additional decarbonization strategies, where available.

[3] Better Buildings. Better Climate Challenge. betterbuildingssolutioncenter.energy.gov/climate-challenge.

[4] EIA. 2012 CBECS Survey Data.



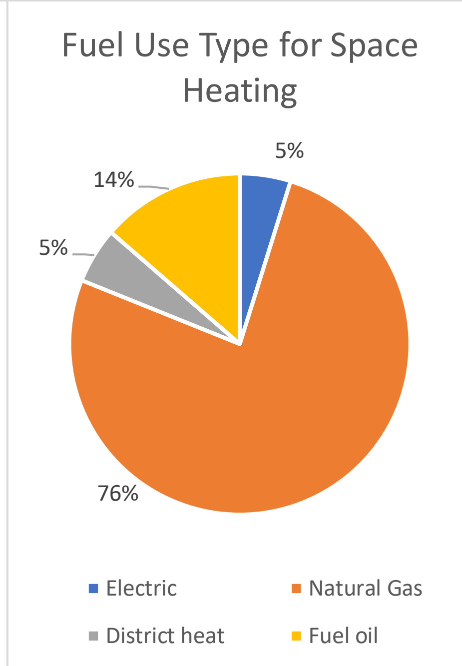


Figure 1: Percentage of annual energy consumption by application and primary space heating fuel type

Key Challenges

1) First cost
2) Operating cost
3) Space constraints
4) Water temperature requirements
5) Heat demand
6) Split incentive

**Discussed in more detail in section 6.2*

Although the topic of commercial building electrification has seen increased interest in recent years, the majority of projects and case studies focus on new construction rather than retrofitting existing systems, which make up the vast majority of commercial buildings. There are several challenges and barriers when retrofitting natural gas boiler systems with electric heating technologies (see call-out box). The cost of electric systems and the necessary capital to retrofit the existing system is one of the major barriers that was cited by all the stakeholders. Also, the relative cost of fossil fuels compared to electricity prices, especially in colder climates, is a barrier for building owners. There are also space limitations when retrofitting for certain systems; for example, high-rise buildings do not have enough space on the roof for the outdoor units of air-source heat pumps needed to meet building loads. There are space and design considerations, such as pipe and valve sizing, that are easier to consider when in the design phase of a new building. With new construction, the building envelope can be designed around the new system based on the performance to ensure efficient operation, whereas with retrofits, the envelope and other efficiency measures would require significantly more updates.

1.2 Goal of this Guidance Document

This guidance document summarizes key considerations for those with existing buildings with hot water or steam boilers who are looking to retrofit their space heating systems to one or more electric heat pump technologies, such as A2W hydronic heat pumps, VRF heat pumps, heat recovery chillers, or other strategies. The guidance document is meant to help building owners, contractors, and other stakeholders involved with HVAC design and purchasing decisions, especially for large, existing commercial and multifamily buildings. The document covers the barriers of implementation, the design/replacement process, the involved stakeholders, potential infrastructure upgrade needs, and feasibility challenges. The ultimate goal of this document is to provide foundational information for building owners to then begin the process to analyze the feasibility of a potential electrification retrofit with their facilities and design teams.

To showcase how electrification is feasible for large existing buildings, the team has also captured a series of case studies for completed and under-development projects across the United States. The authors, DOE, and Better Building partners are interested in profiling additional successful electrification projects and encourage those involved in the design and construction of these projects to reach out to the authors or the DOE Better Buildings program to discuss the opportunity further. If you are interested in working with DOE on this effort, please contact BetterBuildings@ee.doe.gov.

1.3 Methodology

An extensive literature review of more than 20 different reports, case studies, and other documents, in addition to 14 interviews with various stakeholders, helped inform and showcase the current strategies, challenges, and market around boiler electrification. The interviewees included building designers, equipment manufacturers, and other industry experts who provided unique insight into the electrification process. This report summarizes the key strategies, considerations, and challenges identified through the literature review and interviews. See the acknowledgements section for the full list of interviewees and contributors.

2 Commercial Building Types and Segments

Commercial buildings vary drastically in their size and activity, including schools and university buildings, offices, warehouses and storage facilities, hotels, hospitals, etc. A variety of space heating technologies are used in commercial buildings, including furnaces, boilers, space heaters, and heat pumps. Boilers are used as a space heating technology in approximately 703,000 commercial buildings throughout the United States,[5] which accounts for roughly 12% of all buildings in this sector. However, boilers are typically more prevalent in larger buildings and, therefore, account for the heating of about 30% of the floorspace for all commercial buildings[6] and about 32% of the total energy consumption.[7]

Table 1 details the breakdown of space heating energy consumption for U.S. commercial buildings based on size, with a focus on those that use fossil fuel boilers. Although there are many more buildings below 10,000 square feet, medium to large commercial buildings account for over 80% of total commercial space heating energy consumption and have a high prevalence of central boilers.

Table 1: Commercial Building Energy Consumption by Building Size

Building Size (square feet)	Number of Buildings (thousands)	Total Energy Consumption (trillion BTU)	% Commercial Energy Consumption by Building Size	Total Energy Consumption – Buildings with a Boiler (trillion BTU)	% Commercial Energy Consumption for Buildings with a Boiler
1,001–10,000	4,006	1,369	20%	135	6%
10,001–100,000	1,415	2,766	40%	850	38%
> 100,000	136	2,828	41%	1,277	56%

Source: EIA, 2012 CBECS Survey Data

Boilers are common in commercial buildings in all regions of the United States, as shown in Figure 2 and Table 2. However, commercial buildings in the Northeast are more likely to use boilers as the primary source of heating, and buildings in the South are less likely. As such, electrification strategies for large commercial buildings would be applicable for the entire United States, although colder regions will generally require more advanced cold-climate heat pump (CCHP) solutions to satisfy winter heating loads when outdoor temperatures drop below freezing.

[5] EIA. 2018. 2018 CBECS Final Results. www.eia.gov/consumption/commercial/.
[6] Ibid.
[7] EIA. 2012 CBECS Survey Data.

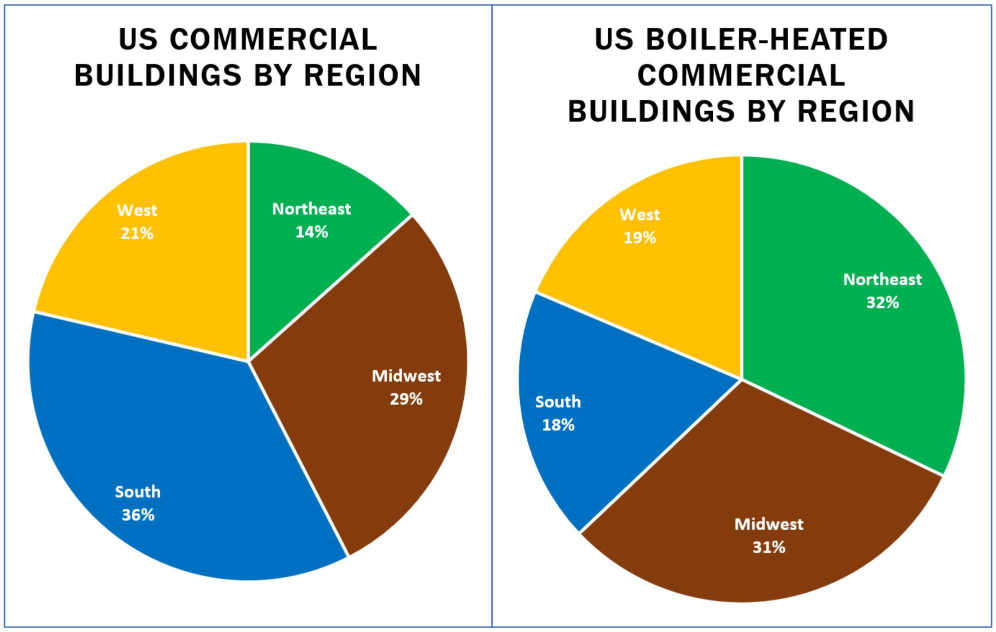


Figure 2: Commercial building breakdown by census region

Source: EIA, 2018 CBECS Final Results

Table 2: Boiler Usage in each Census Region

US Census Region	# of Boiler-Heated Commercial Buildings (thousands)	% of Commercial Buildings with a Boiler
Northeast	**226**	**28%**
New England	95	35%
Middle Atlantic	131	25%
Midwest	**217**	**13%**
East North Central	167	15%
West North Central	50	8%
South	**130**	**6%**
South Atlantic	63	6%
East South Central	20	6%
West South Central	47	6%
West	**131**	**10%**

Mountain	66	14%
Pacific	65	8%

Source: EIA, 2018 CBECS Final Results

Figure 3 and Table 3 outline the prevalence of boilers in each of the major commercial building segments. The likelihood of a building being constructed with a boiler depends on a number of design factors and thus can vary dramatically between building segments. Building segments with the highest saturation of boilers as a percentage of buildings in that segment include in-patient healthcare (i.e., hospitals), education, lodging, public order and safety (i.e., government buildings), and religious worship. In terms of highest number of buildings with boilers nationally, education and office segments account for almost 40% of buildings that use boilers. Large multifamily buildings are another segment that is not included within CBECS, but it has a high prevalence of boiler space heating.

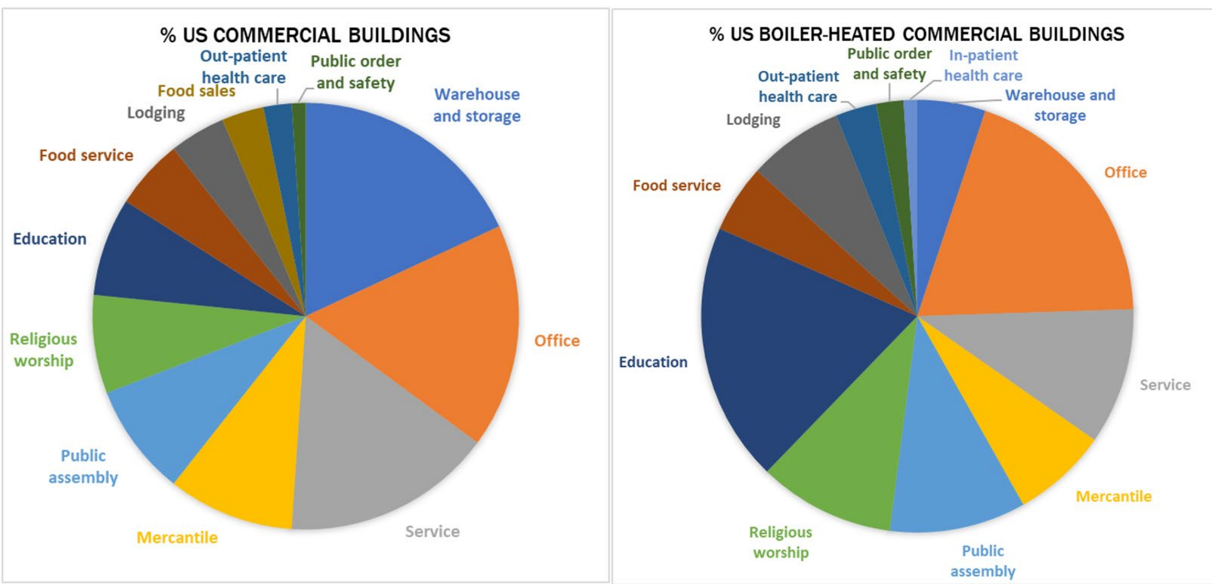


Figure 3: U.S. commercial buildings by segment

Source: EIA, 2018 CBECS Final Results

Table 3: Boiler-Heated Commercial Buildings by Segment

Building Segment	# of Boiler-Heated Buildings (thousands)	% of Buildings that Use a Boiler
Education	133	30%
Office	133	14%
Religious worship	70	16%
Service	69	8%

Public assembly	69	14%
Lodging	50	23%
Mercantile	49	9%
Warehouse and storage	34	3%
Food service	32	11%
Out-patient health care	18	14%
Public order and safety	14	19%
In-patient health care	7	78%
Food sales	1	1%
Total	**703**	**12%**

Shaded building segments are those with > 15% of buildings using boilers.

Source: EIA, 2018 CBECS Final Results

3 Motivations for Electrification

Throughout our expert interviews, stakeholders cited several motivations for building owners doing an electric retrofit of a natural gas hot water system (see call-out box). Achieving the lowest life cycle cost is the most prominent driver for electrification. In addition, local regulations to electrify and reduce emissions are driving building owners to update their systems or conduct feasibility studies to understand what it would take to meet these regulations.

Key Motivations

1) Life cycle cost and energy savings
2) Electrification outlook
3) Regulations, executive orders, and ordinances
4) Incentives and rebates
5) Sustainability goals/commitments
6) Occupant comfort

3.1 Life Cycle Cost and Energy Savings

A major driver for natural gas to electric heating retrofits is life cycle cost savings. There are opportunities across the country where electric space heating might offer lower operating costs today than the current heating system. This is heavily dependent on the building's climate region, utility rates, and the efficiency of their current systems. In the Forum Apartments case study highlighted in section 8, a main motivation was operating cost reduction. By separating from the district heating system and installing PTHPs and electric water heaters, they saw an estimated annual energy savings of $16,700.

Electric heat pump technologies operate more efficiently in moderate climates, so buildings in these regions have more potential for cost-effective electrification. Additionally, buildings with a smaller peak heating load can install less capital-intensive heating systems. Buildings in these regions also may not require changes to their electrical service if the peak cooling load is equivalent to or larger than the peak heating load. Buildings in cold-climate regions are less likely to see life cycle cost advantages from electric retrofits relative to natural gas without considering additional strategies to reduce heating loads, such as envelope improvements. Nevertheless, buildings with higher-than-average fuel costs, including those supplied by fuel oil, propane, or district heating, may also have more opportunity for life cycle cost savings through electrification.

Another important opportunity is for buildings to replace both their gas boiler and central air-conditioning (AC) system at the same time. Most electric heat pump technologies can provide both the heating and cooling needs of a building, which can reduce equipment and installation costs in certain circumstances. Some technologies can also provide space heating and cooling simultaneously, which offers significant potential for buildings with year-round heating and cooling demands, such as hospitals. A detailed building load analysis would be necessary to identify the peak heating and cooling loads throughout the year and assess the attractiveness of different electric heat pump technologies.

3.2 Electrification Outlook

Many owners want to be proactive and prepare their buildings for future electrification, emission, and decarbonization requirements that they predict will be enforced over the next decade. Building owners are incentivized to undergo retrofit projects to stay up to date with the current technology. Many building owners consider the eventual financial burden that regulations may impose in the future when retrofitting their buildings. Although some states and cities may not require electrified water-heating systems, some building owners are anticipating future regulations and attempting to get ahead while demand for the solutions may be lower.

3.3 Regulations, Executive Orders, and Ordinances

Government regulation is an important motivation for boiler retrofit projects. State, local, and federal government policies are pushing building owners to install electrical alternatives and reduce emissions (e.g., Local Law 97 in NY, which sets new aggressive energy efficiency and GHG emissions limits by 2024, with stricter limits coming into effect in 2030).[8] Other states, such as Illinois and Massachusetts, passed legislation that increased ambition for utility efficiency and electrification programs and that require their respective states to develop new stretch codes, which could include all-electric requirements. Ithaca, NY, initiated a major 3-year project to electrify and decarbonize 1,600 residential and commercial buildings beginning in 2021, with a focus on low-income households, and 4,000 more by the end of 2030. Denver passed legislation that requires emissions reductions from all commercial and multifamily buildings via energy efficiency, renewable energy, and building electrification by 2030.[9] An increasing number of states and local municipalities are passing legislation that will require buildings to electrify over the next decade. Many of these policies start first with new-construction electrification goals but will eventually include existing buildings.

3.4 Incentives and Rebates

State governments and electric utilities have different incentives and rebates that lower first cost for gas-to-electric retrofits and more efficient buildings. For example, Sacramento Municipal Utility Department (SMUD) offers incentives for small and large commercial building electrification, including rebates for energy-reduction upgrades on HVAC systems and a custom retrofit "Go Electric" package to incentivize gas-to-electric conversions at a rate of $0.30/kWh-equivalent site energy reduction, with payments of up to 50% of project costs, capped at $100,000.[10] Incentives and rebates make retrofitting gas systems more feasible for building owners by reducing the upfront and/or life cycle costs of the equipment. Building owners interested in sustainability can take advantage of available incentive and rebate programs to increase the economic attractiveness of their electrification projects. Through the Empire Building Challenge, the New York State Energy Research and Development Authority (NYSERDA) is investing $50 million to demonstrate the technical and economic feasibility of retrofitting tall buildings to low-carbon standards. Through demonstration projects, NYSERDA and its partners will deploy low-carbon retrofits to reduce energy consumption.[11] In New York

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[8] City of New York. Local Law 97. www1.nyc.gov/site/sustainablebuildings/ll97/local-law-97.page.

[9] Alter, Abigail. 2021. "A Landmark Year for Building Electrification." RMI. rmi.org/a-landmark-year-for-building-electrification/.

[10] Cohen, C., and N. W. Esram. February 2022. *Building Electrification: Programs and Best Practices*. ACEEE. www.aceee.org/sites/default/files/pdfs/b2201.pdf.

[11] NYSERDA. Empire Building Challenge. www.nyserda.ny.gov/All-Programs/Empire-Building-Challenge.

City, which has a very high concentration of large buildings with boilers, Con Edison is offering rebates and tax incentives for replacing fossil fuel boilers with electric systems.[12]

In the Cook County Forest Preserves case study highlighted in section 8, Commonwealth Edison (ComEd) provided a financial incentive through its emerging technologies program to upgrade the outdated HVAC system. The building is changing out the natural gas boiler system for a VRF system and is expected to see HVAC energy consumption reductions of up to 83%. In addition, the Early 20th Century Manhattan Multifamily Building case study received an estimated $70,000 in rebates from ComEd for upgrading from an oil-fired boiler system to zone mini-split systems.

The availability, amount, and design of these incentive programs will vary by location, and building owners should consult directly with a representative from their state or utility program administrator.

Additional federal incentives are available for commercial buildings that reduce their energy consumption through energy efficiency and electrification measures. The 2022 Inflation Reduction Act (IRA) expanded the existing 179D Energy Efficient Commercial Building Deduction, which provides a tax deduction for existing commercial building owners who reduce their energy use compared to a prior 12-month period. The IRA lowered the minimum required savings from 50% to 25%, expanded the list of eligible projects, and removed the lifetime deduction limit. The deduction can range from $0.50 to $5.00 per square foot of building floorspace, depending on the percentage of energy reduction achieved in the project (25% minimum, up to 50%), whether the contractors meet prevailing wage and apprenticeship thresholds ($0.50–$1.00 per square foot for incompliant projects, $2.50–$5.00 per square foot for compliant projects, and other requirements.[13]

3.5 Sustainability Goals and Commitments

Building owners have made a wide range of sustainability commitments over the last 20 years to address climate change. In order to achieve the emissions reduction goals and sustainability commitments, building owners are exploring electrification strategies across their portfolios. In these situations, the building owners may track an internal cost of carbon or other mechanism where they can view the electrification project in terms of its carbon abatement potential in support of their GHG emissions goals. In these circumstances, any potential higher cost for the electrification upgrade may be acceptable when compared with other abatement projects rather than a baseline fossil fuel heating system. For owners of leased buildings, having a more environmentally friendly building can attract prospective tenants who have their own sustainability commitments.

3.6 Occupant Comfort

Today's heat pump technologies systems have more advanced controls for addressing occupant comfort needs, compared to older systems. According to one interviewee, occupant comfort is a

[12] Con Edison. Savings for Commercial and Industrial Customers. www.coned.com/en/save-money/rebates-incentives-tax-credits/rebates-incentives-tax-credits-for-commercial-industrial-buildings-customers/save-with-energy-efficiency-upgrades.

[13] Dech, Z., and Peer, C. October 2022. "The Inflation Reduction Act Extends Energy Efficiency Building Incentives." Clark Schaefer Hackett. www.cshco.com/articles/the-inflation-reduction-act-extends-energy-efficiency-building-incentives-45l-and-179d/.

key factor that needs to be considered when retrofitting a system, and electrification projects offer the opportunity to significantly improve occupant comfort. More advanced heat pump controls allow occupants to set more detailed schedules for set points in addition to providing grid-interactive capabilities to shed and shift building loads. More detailed scheduling and sensing allow the units to meet tenant comfort requirements more closely. Maintaining a comfortable building environment for the occupants is an important motivation for building owners. Creating comfortable indoor environments is critical to the happiness and productivity of its users. Often factors such as airflow and radiant temperature are overlooked in a design, leading to higher energy use and occupancy dissatisfaction.[14] Occupants of leased buildings with lower comfort levels are less likely to remain in the space, which would impact the building owner's ability to keep the building occupied.

Some multifamily buildings particularly struggle with occupant comfort when their heating is sourced from district steam or hot water, as the building's distribution systems are typically old and provide unreliable heat. One opportunity for buildings with multiple tenants is to install PTHPs or ductless heat pumps for each unit, which allows each tenant to easily control the temperature of their space for optimum comfort. The Early 20th Century Manhattan Multifamily Building case study highlighted in section 8 showcases a successful project that replaced an oil-fired boiler system with ductless mini-splits.

3.7 Maintenance Savings

New electric systems can potentially reduce maintenance costs and labor hours through improved controls and simplified systems. Maintenance tends to be more difficult with older HVAC technologies, especially those using older control technologies. According to a stakeholder, moving away from a hydronic system has saved maintenance costs, because there are fewer water leaks when switching to a VRF system. Also, in some cases where a building uses a steam system in conjunction with window AC units, switching to a VRF and dedicated outdoor air system (DOAS) would save maintenance and labor time from fixing, installing, and removing window AC units every year.

[14] The Autodesk Foundation. Occupant Comfort. sustainabilityworkshop.venturewell.org/node/1006.html.

4 Electric Space Heating Technologies to Replace Fuel-Fired Boilers

Boilers used for commercial buildings in the United States are typically fossil fuel fired, with the fuel being primarily natural gas (90% of commercial boiler space heating energy).[15] Each building is uniquely designed and requires a unique solution, and therefore, a number of electric heating technologies with architectures similar to fuel-fired boilers exist that may be the best design option.

4.1 Characteristics of Fuel-Fired Boilers

Figure 4: Commercial fuel-fired boiler

A fuel-fired boiler uses the combustion of a fossil fuel such as natural gas to increase the temperature of a hydronic loop. Some boilers produce steam, whereas others produce hot water, typically in the temperature range of 160–180°F. The steam or hot water is then distributed throughout the building to radiators, typically in each room, which radiate the heat to the surrounding area. Different system designs can be used to distribute the heat to each room, such as wall radiators, baseboards, and radiant flooring. Steam systems are typically less efficient than hot water systems but are typically better at transferring heat to each room. Boilers and hydronic distribution networks may also provide the heating input for rooftop units (RTUs), air handlers, or VAV boxes for forced-air ducted heating systems.

4.2 Characteristics of Electric Heating Technologies

A variety of electric heat pump and resistance technologies are available to provide space heating to buildings while substantially reducing or eliminating the traditional direct use of fossil fuels. Options are available for buildings using hydronic, centrally ducted, and in-room distribution systems. However, changes to the building's infrastructure, particularly the thermal distribution network, are almost always required before swapping out a fuel-fired boiler for an electric technology.

Multiple electric space heating technologies can be considered to replace fuel-fired boilers, either as an individual technology or in coordination with other electric technologies, including:

- A2W heat pumps
- Heat recovery chillers
- VRF systems
- Electric boilers
- PTHPs.

[15] EIA. 2012 CBECS Survey Data.

4.2.1 A2W Heat Pumps

A2W or hydronic heat pumps generally use a vapor compression cycle to generate hot water and distribute it throughout the building to radiators, VAV boxes, and other heat exchangers that are able to heat the surrounding area. This technology uses a building infrastructure similar to that of a fuel-fired boiler, except with electricity as the energy source. Current A2W heat pump technologies are able to provide hot water output temperatures in the range of 120–130°F, which is lower than the high-temperature water typically provided by a boiler (~ 180°F). The hot water distribution infrastructure may need to be upgraded accordingly to match the thermal output of a lower-temperature hydronic loop, but it is possible for there to be sufficient radiator area to accommodate the lower temperatures. Another strategy utilizes A2W heat pumps to provide heat input to a centralized water loop that connects with floor-by-floor or in-unit water-source heat pumps in a cascade heat pump design. Retrofitting a boiler system to a hydronic heat pump system often requires a number of additional infrastructure upgrades to provide effective comfort, such as building envelope insulation, window, and air leakage improvements.

While this guidance document focuses on space heating technologies, manufacturers also offer A2W and water-to-water heat pumps for domestic hot water needs in large commercial and multifamily buildings. In recent years, the number of manufacturers and variety of products offered has increased significantly, including those using low global warming potential (GWP) refrigerants, such as R-513A and R-744 (carbon dioxide).

4.2.2 Heat Recovery Chillers

Chillers are large vapor-compression systems that generate and distribute chilled water for building space cooling. Heat recovery chillers are able to recover the heat that is removed from the chilled liquid and simultaneously produce hot water, which can be distributed throughout the building to provide space heating (Figure 6). The figure below provides a schematic of a heat recovery chiller design. Heat recovery chillers are typically a solution for larger buildings or campuses, such as colleges and universities, hospitals, and large office buildings that have existing chilled and hot water networks and year-round heating loads for space and/or centralized water heating. Most heat recovery chillers are water-to-water designs, although there are some A2W designs as well.

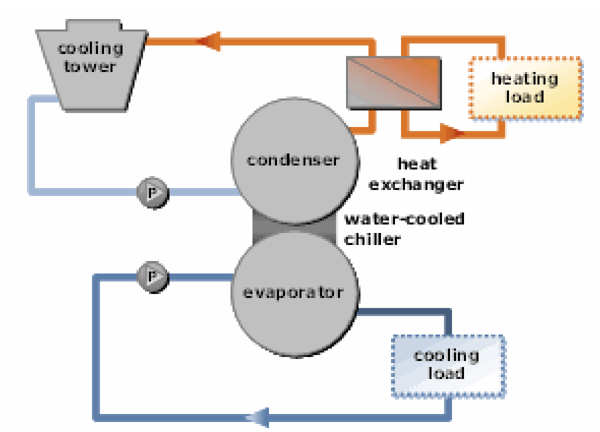

Figure 5: Heat recovery chiller diagram[16]

[16] Jia, J. November 2006. "Introduction of Heat Recovery Chiller Control and Water System Design." Presented at the Sixth International Conference for Enhanced Building Operations, Shenzhen, China. oaktrust.library.tamu.edu/bitstream/handle/1969.1/5243/ESL-IC-06-11-104.pdf?sequence=4&isAllowed=y.

4.2.3 VRF Systems

VRF systems distribute refrigerant to conditioning units in individual zones throughout the building, as opposed to packaged systems that condition and distribute air throughout the building for comfort. Buildings using VRF systems typically have an alternative ventalation system to take in and filter the outdoor air, often using a DOAS that may include an energy recovery ventilator (ERV). VRF systems have a key asset in that they can provide heating and cooling simultaenously to different zones of a building, as is shown in the figure below, and they are commonly installed in buildings that have hydronic heating and no forced-air duct systems. A change from a fuel-fired boiler to a VRF system requires a complete redesign of the heating system architecture. The hydronic pipes of the boiler system would need to be completely removed or abandoned for new refrigerant tubing to support the VRF system design.

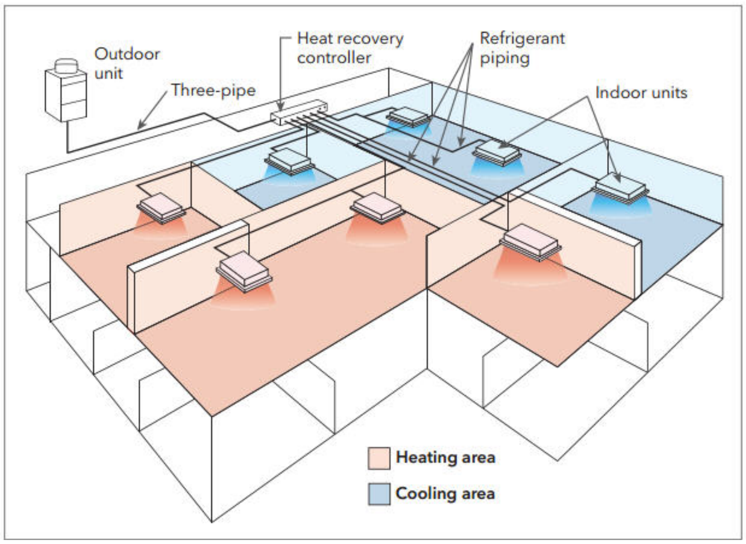

Figure 6: VRF system schematic[17]

While most VRF systems use R-410A today, newer hybrid-VRF technologies can enable the wider use of refrigerants with lower GWP, such as R-32, by introducing a refrigerant-to-water heat exchanger and small-diameter hydronic loops to indoor conditioning units.[18] This strategy limits the amount of refrigerant circulating throughout the building, while still allowing the zone-level control and retrofit capabilities of VRF systems.

4.2.4 Electric Boilers

An electric boiler system uses electric resistance heating to generate hot water and distributes the water throughout the building similarly to a fuel-fired boiler. Electric boilers are a simpler heating solution with the most potential to directly replace a natural gas boiler. These systems typically have a lower capital cost than electric heat pumps but are likely to have much higher energy costs throughout their lifetime, due to the lower efficiency of resistance heating (coefficient of performance [COP] of 1) compared with heat pump heating (COP of 3 or greater). They may also require substantial electrical infrastructure upgrades to accommodate the large increase to the electric load, especially for buildings in moderate- and cold-climate regions.

[17] Slipstream. Variable Refrigerant Flow (VRF). slipstreaminc.org/tags/variable-refrigerant-flow-vrf.
[18] Mitsubishi Electric. What Is Hybrid VRF? www.mitsubishi-electric.co.nz/hvrf/r32-hvrf-what-is-hybrid-vrf.aspx#:~:text=Hybrid%20VRF%20is%20a%20unique,Controller%20and%20the%20indoor%20units

Buildings using A2W and other hydronic heat pumps may require auxiliary electric boilers to supplement heating capacity during extreme cold conditions.

4.2.5 PTHPs

PTHPs are packaged solutions that provide heating and cooling to each individual room of a building. This technology is common for hotels and apartment buildings where the temperature of individual spaces can be controlled by the occupant of the room. PTHPs do not have a central distribution network of any kind, as they are installed directly through the walls of the building. Therefore, the hydronic pipes of an existing boiler system would need to be completely removed or abandoned, and the central boiler room would not have any direct replacement technology. PTHPs are a good heating retrofit solution for buildings that are currently using these types of technologies or have their cooling currently provided by packaged terminal air conditioners (PTACs). Other similar technologies include vertical terminal air conditioners and vertical terminal heat pumps (VTHPs), which are typically installed in a hidden space such as a closet, as well as window or through-the-wall air conditioners and heat pumps.

4.2.6 Additional Technologies

Other less common technologies can be used in specific cases where there are no project constraints on available space or time. GSHPs operate more efficiently than the more common air-source heat pumps (ASHPs) but require a ground loop to be installed, which can be capital, space, and time intensive. Other technologies, such as underground thermal storage can contribute significantly to lowering energy bills, but they also are constrained by the available space for the storage medium and their capital intensity.

5 Boiler Retrofit Evaluation and Process

The process of switching the heating system of an existing building can often be complex. Each building is unique and comes with its own set of considerations. Exploring a retrofit project starts with understanding the existing building system. Some typical questions that need to be answered before beginning the retrofit include:

- What is the existing heating source?
- Where is the system located?
- What are the building's heating requirements?
- What is the building's electric infrastructure?
- What is the project budget?

5.1 Key Stakeholders

A variety of stakeholders can be involved in any building retrofit process, including the following:

- **Building owners** are ultimately in charge of the decision-making process.
- **Engineering firms, design consultants, and architects** determine the best HVAC system designs, perform energy studies, and complete M&V studies.
- **Contractors** provide the installation of the new technologies.
- **Utilities and state and local governments** provide indirect contributions through incentives, grants, rebates, tax credits, etc.

Converting a boiler to an electric system may be an unfamiliar process for many building owners and system designers, but the overall process is similar to that of other construction projects for existing buildings. The key stakeholders involved are the same, but the project life cycle may be more significant than a like-for-like boiler replacement, depending on the complexity of the project. A beneficial first step when retrofitting a building or system is to address any areas where efficiency can be improved before changing out the system and sizing equipment. Making the building efficient through envelope upgrades or other strategies should be the first priority to lower the building energy requirements. Insulation and air-sealing investments can reduce HVAC capacity needs and system costs before replacing the equipment, which can have cascading impacts on project economics and feasibility (e.g., smaller heating loads allow for downsizing of heat pump equipment, which requires less physical space and electrical infrastructure). After the building is assessed for efficiency upgrades, a capital plan should be developed to ensure funding the retrofit is feasible. It is also helpful to consider nonenergy benefits, including indoor air quality and health, operations and maintenance, comfort, productivity, and grid integration.

5.2 Project Life Cycle

Retrofit projects almost always begin with a feasibility assessment carried out by the engineering firm or design consultant. These assessments typically take 2–3 months and are necessary to understand the layout of the building infrastructure. This phase is followed by a design phase in which the engineers determine the best possible solution for the building, which typically lasts an additional 3–5 months. The design phase is followed by the construction phase, which can last anywhere from 3 months to over 1 year to complete, but this varies greatly from building to building. Figure 8 shows the project timeline and describes some of the involved stakeholders.

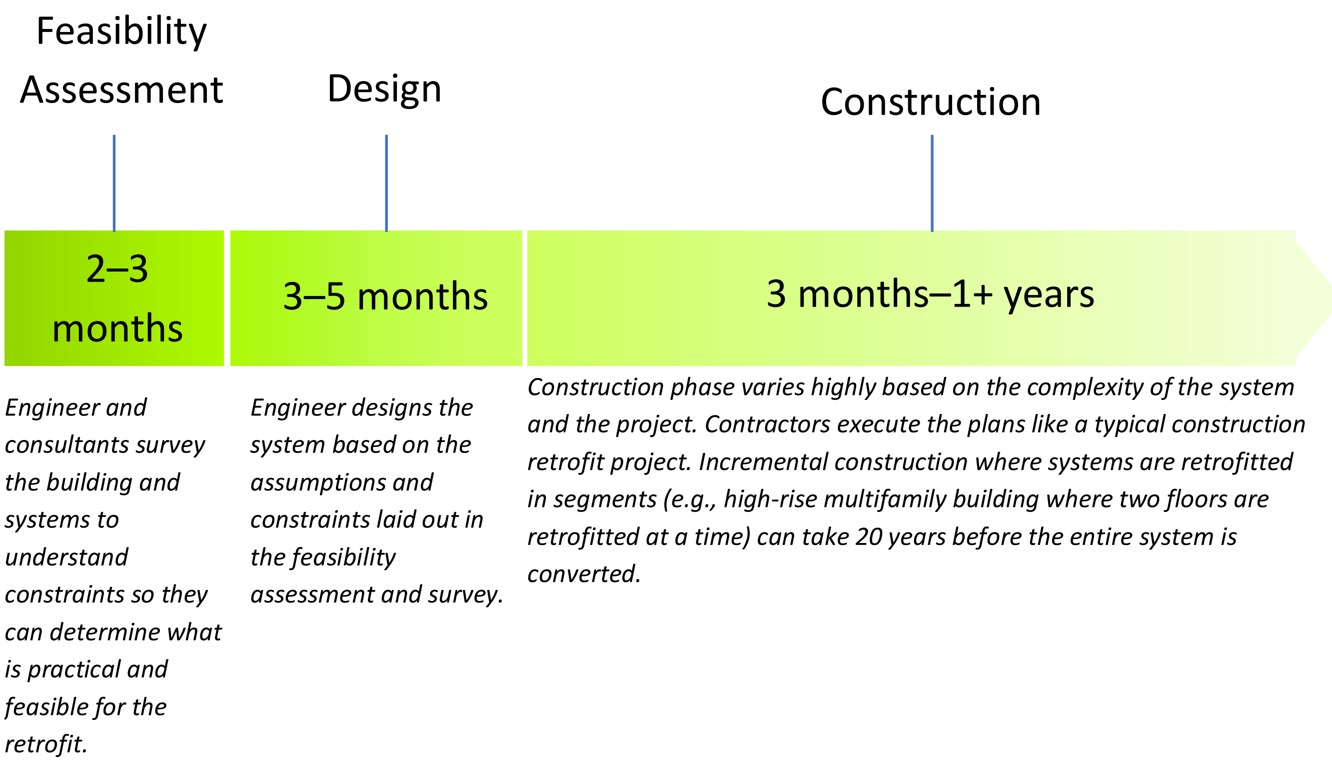

Figure 7: Retrofit project life cycle

Project timelines can vary greatly depending on the building size, age, and required upgrades. Additionally, building owners sometimes can choose to extend the project over a longer period of time to spread the required infrastructure upgrade capital costs. Some projects can even be spread over the course of 20 years while continuing normal business operation, as is further described in section 6.1.3. Large buildings with multiple tenants might see an advantage with this incremental approach by upgrading each unit of a building in between tenant occupation.

5.3 Feasibility Assessment and Infrastructure Upgrade Requirements

Every commercial building is unique and requires an individual evaluation to determine the proper retrofit strategy. Each solution will be specific to the building, but the approach to finding the proper solutions can be replicated. The feasibility assessment includes understanding the type and quantity of fuel being used for the existing heat system and what time of day/month of the year have the largest heating load. This is important for understanding how the building is operating before planning for retrofit options.

The project engineers will also need to see the layout of the building's current heating and cooling systems to decide what electric technologies can be considered. This might involve viewing the current hydronic distribution network and physical sizing and layout of the mechanical room, evaluating the building's insulation levels, or checking the electrical panel capacity, among many other considerations. Sometimes the individual components of the existing systems (e.g., pumps, VAV boxes, controls) can continue to be utilized, so the engineer will need to evaluate the performance of these components first. Keeping as much of the current building's infrastructure as possible is important for reducing the overall project cost.

5.3.1 Thermal Distribution Temperatures

It is important for the design engineers to know the temperature of the water used in the hydronic distribution network. Many existing buildings are likely to run their systems with 180°F water. However, several interviewees report it is possible to provide an equivalent or similar level of heating in many buildings with lower temperatures in the range of 120–150°F. This is an important consideration, because the performance and efficiency of A2W heat pump technology improves at lower supply temperatures.

5.3.2 Energy Efficiency Upgrades

The project engineers will likely want to understand the amount of heat being lost out of the building, as this has a direct effect on the heating capacity required for the new building HVAC design. This includes evaluating the building envelope and insulation, as well as determining opportunities for heat recovery (e.g., ERV to precondition outside air). Building envelope upgrades could also provide load reduction and improved occupant comfort by better insulating the building.

5.3.3 Electrical Service

Electric heat pump systems typically have higher electrical requirements than the building is designed for with fuel-fired heating systems, especially if auxiliary electricity resistance heating is installed. In some cases, the electrical infrastructure upgrades required to switch from a natural gas or steam-based system to an electric system could become a limiting factor on the feasibility of the project. This is especially true in colder climates where the maximum heating load is much larger than the maximum cooling load, and auxiliary electric resistance heating may be needed to supplement heat pump capacity lost during extremely cold weather. The project engineers will need to understand the current electrical service capability of the building and determine the amount of additional load that will be expected with electric heating. The building will need to upgrade to a larger-capacity electrical panel if the current service within the building is not sufficient. In some cases, the project may need to involve the local utility to upgrade the total service provided to the building. This can often be a difficult barrier based on the cost of upgrading the infrastructure in addition to the system retrofit and may pose feasibility challenges in dense urban areas.

5.4 Design and Construction

Once the feasibility assessment is finished, the design phase begins. The design engineers and consultants use the information gathered from the feasibility assessment to lay out the system. After the design phase, the contractors begin to implement the design and physically retrofit the building. The design and construction phases are comparable to that of typical construction and retrofit projects.

6 Project Considerations

There are several challenges and barriers that building owners and designers should consider when starting a retrofit project or feasibility assessment. Based on conversations with several stakeholders, the team developed a list of key strategies that could help accelerate the adoption of electrifying boiler systems, as well as the most common barriers and constraints that stakeholders have seen or anticipate. Some of the key considerations to analyze are building space constraints, infrastructure impacts, capital and cost constraints, project timeline considerations, and payback considerations. Figure 9 outlines the main factors that building owners should consider when evaluating the feasibility for electrification retrofits.

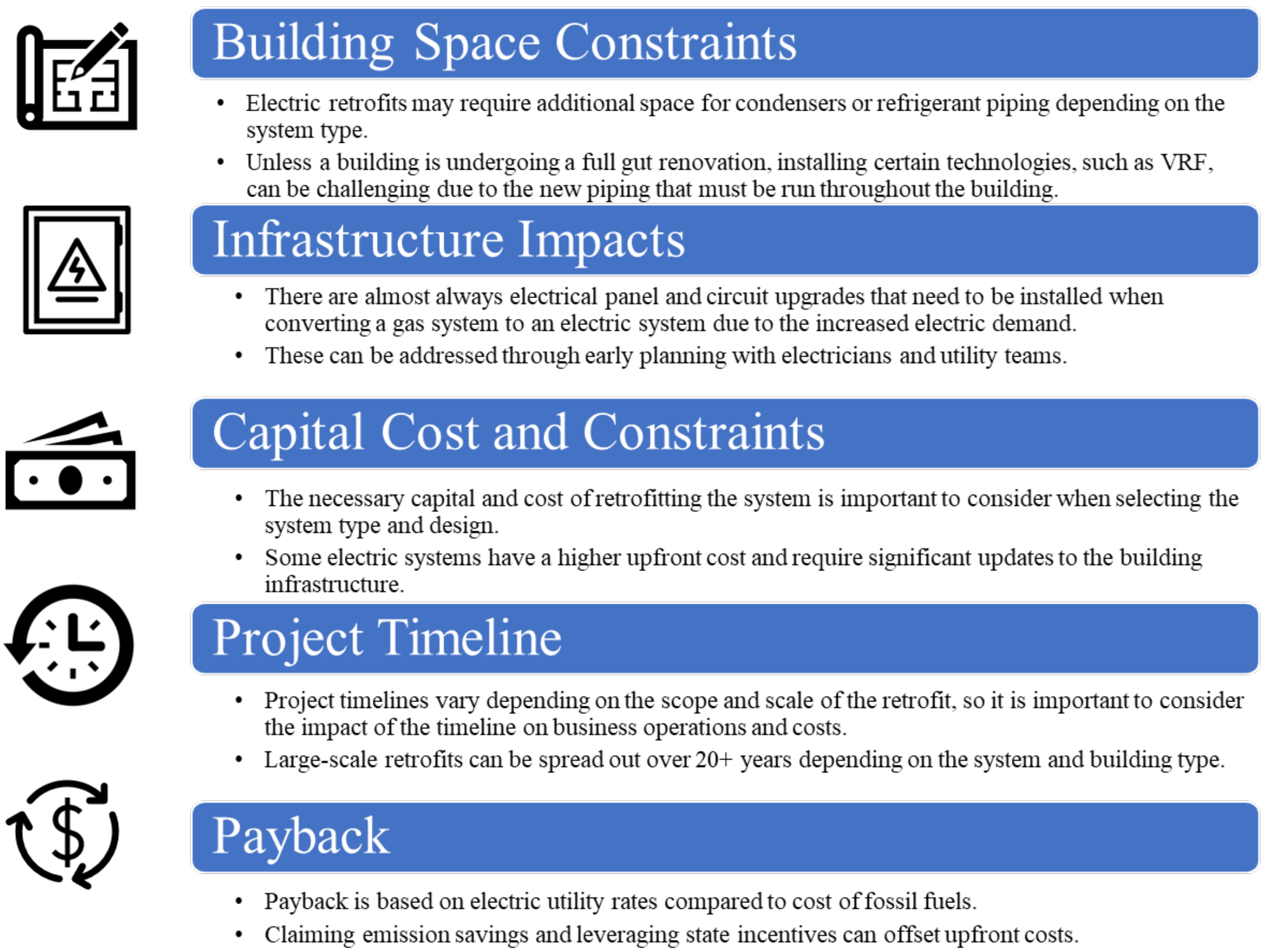

Figure 8: Key considerations for system retrofits

6.1 Key Strategies for Electrification Projects

Many successful strategies can be considered to ease the burden of retrofitting a boiler system. Several interviewees noted that a one-to-one swap of a boiler with a heat pump is unlikely to provide the required levels of comfort heating and will likely not be the best solution from a financial perspective. Removing the hot water pipes from the building and installing ductwork or VRF refrigerant piping can be very expensive and will almost certainly require building tenants to not occupy the building for weeks or months. It is important to consider all the design options to avoid some of the costs associated with a gut renovation unless it is already planned as part of a larger project (e.g., large conversion from one activity to another, build-out for a new tenant). Any upgrades (e.g., larger heating terminal units) that eventually enable the direct conversion to an A2W heat pump with the current infrastructure are important to consider.

Figure 10 lists some of the key strategies and considerations that have been successful when retrofitting a building's hot water system. The successful strategies are described in more detail in the following subsections.

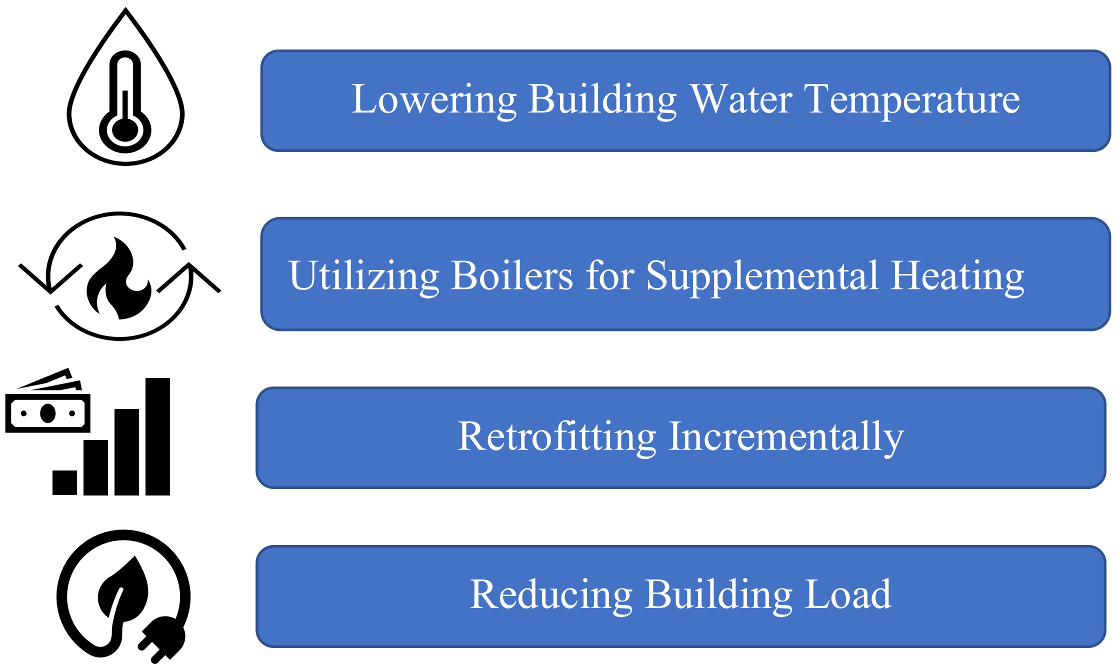

Figure 9: Key strategies and considerations for implementing boiler retrofits

6.1.1 Lower Building Water Temperature

Many buildings can upgrade the existing hydronic distribution network with minimal changes to provide an equivalent level of heating with a lower hot water temperature. Temperatures in the range of 120–150°F can often provide sufficient heating for a building instead of the traditional 180°F, according to design consultants. Lower hot water temperatures (110–130°F) can be achieved with current electric heating technologies, such as A2W heat pumps.

An important strategy is to incrementally lower hot water temperatures and test building operation and comfort to see what hot water temperature is actually required. This can also help with increasing the energy efficiency of the building by optimizing its heating performance. Finding the proper temperatures that can provide comfortable heating on non-peak days can reduce the amount of energy consumed by the system and provide the proper level of comfort.

In some cases, each individual floor or part of a building may require different hot water temperatures or supply rates, given the orientation and loads of each floor (e.g., larger spaces may require higher-temperature water and emitters than smaller spaces). Technologies such as blend-down valves can be used for buildings to operate each floor's supply with different-temperature water. This would not be a major expense to add, as control valves are typically already used at each floor.

Running systems at lower hot water temperatures in some cases would require changes to the fan coil units or VAV boxes at the end of the thermal distribution network. This would ensure that the same level of heating is provided with a lower temperature distribution. Incrementally lowering the water temperature and testing the comfort levels and heating output would help building owners evaluate how low they could drop the water temperature without having to make costly adjustments.

6.1.2 Supplemental Boiler Heating

One strategy to help with electrification would be to make the boiler a supplemental heating source rather than the primary source. The supplemental heating system would only be used during outages and high peak periods, which could lower the operating hours and save operating costs for the electrical systems. Changing boilers to electric resistance boilers is the cheapest first cost and simplest retrofit, but the high ongoing electrical cost makes it impractical. The building could utilize an existing or new fossil fuel boiler as a supplemental resource and still achieve significant GHG emissions reduction, as the supplemental boiler may only operate over a small portion of the heating season. Having a supplemental fossil fuel boiler to offset the electrical demand during peak periods and outages would lower the electrical consumption and offset operating costs, which may potentially improve the economics for the electrification project.

6.1.3 Incremental Retrofit

Upgrading systems gradually over time can help spread the cost of an electrification project over a more manageable time frame. For example, when retrofitting a system that serves multiple floors, one can break up the project to replace the components on each floor separately (e.g., a floor retrofit per year). Completing a large-scale electrification project with various upgrades can be daunting, especially while attempting to sustain normal business operation. Very few buildings are able to switch directly from a fuel-fired boiler to electric heat pump technology with no additional upgrades. Upgrading one component at a time can help put the building in a better position to fully swap out the boiler for an electric heat pump.

The NYSERDA Empire Building Challenge has highlighted resource-efficient decarbonization strategies with incremental retrofit steps such as insulation upgrades, energy recovery, heat pump installation, and complete electrification (Figure 11). This strategy recognizes that decarbonization of existing large buildings is a complex engineering, financial, and logistical process, especially when the building must still provide normal function to tenants during the construction process. The NYSERDA team first recommends a comprehensive review of the building's heating and other loads, as well as existing infrastructure, to understand options for electrification and energy efficiency and energy recovery opportunities. Since many large buildings have pre-established capital-planning cycles for replacing boilers and other building systems, the team advocates for starting this process many years in advance of the boiler replacement. This way, the building loads could be reduced through energy efficiency or energy recovery to reduce the size of the electric heat pump solutions. Furthermore, the team suggests that full electrification may not be feasible for all buildings during the first replacement cycle, and the building may need to maintain an auxiliary fossil fuel or electric resistance heating system for peak days. Nevertheless, the team anticipates that decarbonization technologies may continue to improve over the coming decades such that the building may be able to forego these auxiliary systems, either through heat pump improvements or additional energy efficiency and energy recovery opportunities.

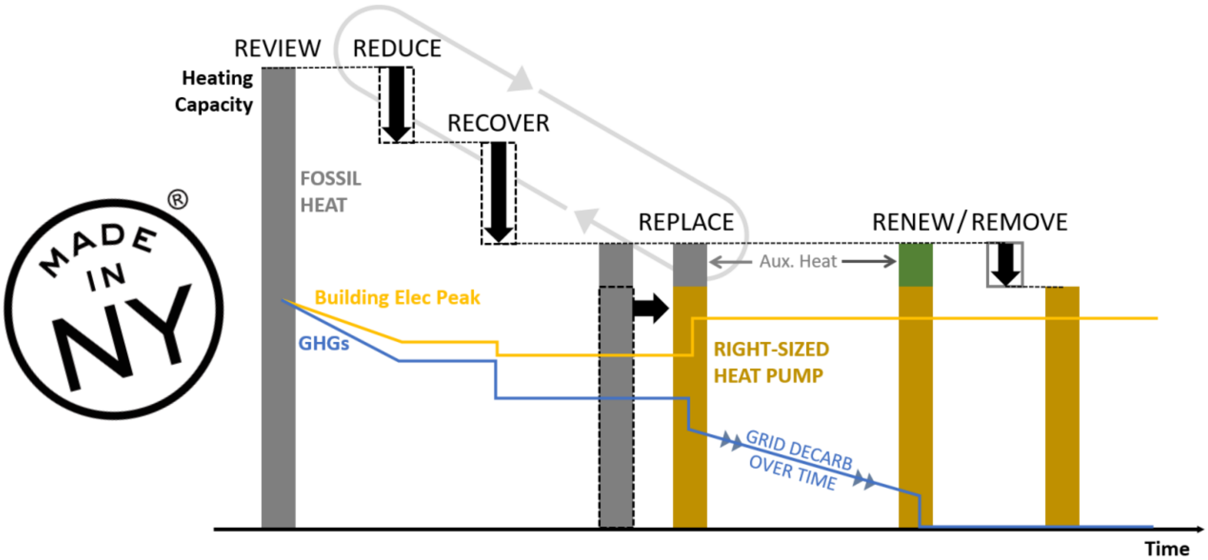

Figure 10: Incremental electrification strategy[19]

6.1.4 Reduce Building Load

As previously discussed, a key strategy to electrifying a building is to first make the building more efficient through other upgrades. Implementing efficiency upgrades, including envelope upgrades, insulation additions and improvements, and rejected heat recovery, can contribute to lowering the building heating load and will require less heating capacity. This is helpful for reducing the size of both the required electric heating technology and the upgraded electrical panel. Lowering the peak demand of the heating system greatly decreases the capital investment required for the heat pump. These efficiency improvement strategies are particularly important in colder climates.

6.2 Constraints and Challenges

There are various constraints and challenges to keep in mind when performing a feasibility analysis for retrofitting a building from a gas boiler system to an electric heating system. While most, if not all, electric heating technologies can be considered for new construction, there are more constraints on existing gas systems that are being retrofitted.

Key Challenges

1) First cost
2) Operating cost
3) Space constraints
4) Water temperature requirements
5) Heat demand
6) Split incentive

6.2.1 First Cost and Capital

First cost is often cited as a major barrier for a natural gas-to-electric retrofit. Raw construction costs and initial investments in new technologies are important considerations when updating

[19] NYSERDA. Building Decarbonization Insights. www.nyserda.ny.gov/All-Programs/Empire-Building-Challenge/Building-Decarbonization-Insights.

building systems.[20] Electrical panels often need to be upgraded to compensate for the added electrical load from the converted system, which increases the upfront cost. This is especially relevant for buildings that do not have AC installed today. Certain systems, such as VRF, are costly to retrofit unless doing a full gut renovation, because new piping must be routed through the building to carry refrigerant that will provide the heating source.

Electrification is most cost-effective for new construction projects, when the building can be designed around a single HP technology that can provide both cooling and heating, and in places with mild winters.

6.2.2 Operating Costs

Electric heat pumps are able to operate more efficiently than fuel-fired heating systems, particularly in warmer climates. Some buildings may see operating cost benefits from the comprehensive retrofits. However, electricity is often more expensive than natural gas, to the point where the energy savings sometimes do not make up for the relative increase in utility rates. This is particularly true for colder climates that will see a more significant increase in electricity consumption, which can be a disincentive for building owners to switch their heating systems. Buildings in colder climates face challenges due to decreased performance and efficiency during colder weather and the potential need for electric resistance or other auxiliary heating systems during extreme conditions. According to interviewees, electric heat pumps generally have lower life cycle costs in the West and South, but natural gas technologies have lower life cycle costs in the Northeast and Midwest. The comparison of heat pumps against fuel oil, propane, district heating, or electric resistance heating will generally be more favorable than natural gas. Each building owner and design team should consider the fuel and utility rates applicable for their location.

6.2.3 Space Constraints

Some buildings have a limited amount of space to install new heat pump systems. This is often true for the central boiler room as well as the thermal distribution network throughout the building. Tall high-rise buildings also face space constraints because of the limited available area on the rooftop for air-source heat pump outdoor units and other equipment. Advanced solutions with thermal storage, geothermal loops, or other innovative technologies may also be prohibited by a lack of available space.

6.2.4 Water Temperature Requirements

Electric systems may have difficulty meeting the 180°F water temperatures that some existing buildings use today. However, an engineering analysis prior to a system retrofit often reveals that a building can provide the same level of comfort with water temperatures lower than 180°F. Nevertheless, steam distribution systems must often be converted to hot water to enable the use of the lower-temperature A2W heat pumps.

6.2.5 Heat Demand

Commercial buildings with large heat demand require heat pumps with large capacities, which can lead to an expensive capital cost. Additionally, buildings that transition from natural gas to electric heating service often require electrical panel upgrades to accommodate the increased

[20] According to a stakeholder, upgrading to new technologies can cost $20–50 dollars per square foot to convert a system. For a 50,000 square foot building, an upgraded system could cost $1 million–$2.5 million. No point of comparison was provided for the cited $/square foot.

demand. This can be especially challenging for buildings such as hospitals that already have high energy use intensities (EUIs). Finding solutions to lower the heating demand is an important strategy for increasing the adoption of electric retrofit technologies.

Buildings in cold-climate regions likely have a more difficult process to switch to electric heating. The heating capacities required for buildings in these regions are more difficult to achieve with ASHPs.

6.2.6 Split Incentive

There is a lack of owner support for investments that will only benefit the tenant and occupants. The building owner would need to supply the capital investment for a new heating system, but the owner does not pay the utility bills and would not see any of the energy cost savings that would result from the retrofit. This also applies for projects focused on energy efficiency improvement (e.g., building envelope improvements, insulation upgrades, energy recovery). There would need to be some form of incentive for a building owner to justify these capital costs.

6.2.7 Workforce

Some building designers and contractors are not as familiar or comfortable with installing newer electric technologies compared to natural gas systems. There is a lack of training in the industry for retrofits from gas to electric systems, which makes the supply of contractors who are well suited to install and perform these retrofits lower. This leads to an increased price for performing the work in addition to less certainty in the execution. This is especially true for technologies such as VRF systems, CCHPs, and dual-fuel heat pumps.

Maintenance availability is also a concern for heat pump systems. The typical maintenance workforce is not as familiar with repairs to electric technologies compared to natural gas systems, especially for facilities that have internal maintenance staffs. Even regions that commonly have electric heat systems, such as the Southeast, are more focused on electric resistance of packaged systems as opposed to A2W heat pumps and VRF systems.

7 Summary and Conclusions

This guidance document is designed to help building owners, contractors, and other stakeholders involved with HVAC design and purchasing decisions, especially for large, existing commercial and multifamily buildings. The goal of this document is to provide foundational information for building owners to then begin the process of analyzing the feasibility of a potential electrification retrofit with their facilities and design teams. The guidance document helps inform and showcase the current strategies, challenges, and market around boiler electrification by using information gathered from an extensive literature review of more than 20 different reports, case studies, and other documents in addition to 14 interviews with various stakeholders. The interviewees included building designers, equipment manufacturers, and other industry experts who provided unique insight into the electrification process.

In future years, a greater number of building owners will consider decarbonization solutions for their large existing buildings based upon state and local regulations, utility incentives and rebates, or organizational sustainability commitments. Other building owners may simply have outdated space heating systems and may be looking to improve building comfort or decrease utility bills and maintenance costs. A2W heat pumps, heat recovery chillers, VRF heat pumps, electric boilers, and PTHPs are all commercially available solutions for use in buildings currently using fuel-fired boilers. Additional technologies are available for use in specific cases where there is sufficient space available and there is a long-term timeline available for the project.

There are a number of considerations throughout the boiler retrofit process, with a variety of different stakeholders involved, as shown in Table 4. The design team must consider these factors throughout each stage of the project life cycle to ensure a successful electrification project.

Table 4. Boiler Retrofit Project Checklist

Project Stage	Lead Stakeholder	Key Considerations
Feasibility Analysis	Engineer or design consultant	• Peak heating loads • Building layout • Thermal distribution temperatures • Insulation and energy efficiency • Electrical service
Design	Engineer or design consultant	• Heating technology decision (A2W HP, VRF, PTHP, etc.) • Necessary energy efficiency upgrades • Electrical service upgrades
Construction	Contractor	• Installation of the new electric system • Additional upgrades that may be required
Incentives and Rebates	Utility or state/local government	• Financial incentives or cash rebates that may be received for completing these projects

The switch from fossil fuel-fired boilers to electric heating technologies comes with challenges, but a number of strategies and opportunities are available to help with implementation. Table 5 describes the challenges and potential strategies to address and mitigate the barriers for adopting all-electric solutions. Building owners are increasingly interested in decarbonizing their building portfolios, and the number of electrification projects for large, existing commercial buildings will increase in future years. Where challenges exist today, manufacturers and system designers will continue to innovate and find cost-effective solutions to achieve the decarbonization goals. Despite these challenges, building owners who make the switch from fossil fuel-dependent boiler systems to high-efficiency heat pumps and other electric technologies will have lasting emissions benefits for their facilities, tenants, and communities.

Table 5: Challenges and Strategies for Boiler Retrofits

Challenge	Strategy
Most hydronic heat pumps are unable to produce hot water in the necessary temperature range of ~ 180°F without auxiliary heating systems.	Some existing hydronic distribution networks can be adapted to provide equivalent heating comfort with **lower-temperature water** (120–150°F).
Large buildings with large peak heat demands require high-capacity heat pumps, which are capital intensive.	**Building efficiency measures** such as insulation upgrades and heat recovery can reduce the building heating load, reducing the capacity and cost of the installed heat pumps.
The capital cost to install an electric heat pump is likely larger than that of a fuel-fired boiler.	Heat pumps operate much more efficiently than fuel-fired boilers and can allow for **operating cost savings** in many regions of the country.
The first cost of a gas-to-electric retrofit can be large and may disincentivize building owners from exploring project options.	Spreading out the decarbonization project over multiple stages as an **incremental retrofit project** can lower the initial cost burden and disruption to existing tenants while also incorporating greater energy efficiency to make an easier transition to electrification.

8 Case Studies of Example Projects

To showcase how electrification is feasible for large existing buildings, the team has captured a series of case studies for completed and under-development projects across the United States. This section contains summary case studies for five electrification projects for existing large commercial buildings in different geographic regions. Table 6 and Figure 12 outline key details for each case study.

The authors, DOE, and Better Buildings partners are interested in profiling additional successful electrification projects and encourage those involved in the design and construction of these projects to reach out to the authors or the DOE Better Buildings program to discuss the opportunity further. If you have are interested in working with DOE on this effort, please contact BetterBuildings@ee.doe.gov.

Table 6: Key Details for Existing Building Electrification Case Studies

Section	Project Name (Building Owner)	Building Location	Primary Contact (Organization)	Building Size (Square Feet)
8.1	Forum Apartments (Colorado Coalition for the Homeless)	Denver, CO	Celeste Cizik (Group14 Engineering)	49,791
8.2	Cook County Forest Preserves General Headquarters	River Forest, IL	David Cohan (Institute for Market Transformation)	23,200
8.3	Manhattan Multifamily Building (Co-op, tenant owned)	New York, NY	Jon Hacker (Daikin U.S.)	9,690
8.4	East Palo Alto Government Center (County of San Mateo)	East Palo Alto, CA	David Heinzerling (Taylor Engineers)	50,000
8.5	Confidential	Mountain View, CA	David Heinzerling (Taylor Engineers)	125,000

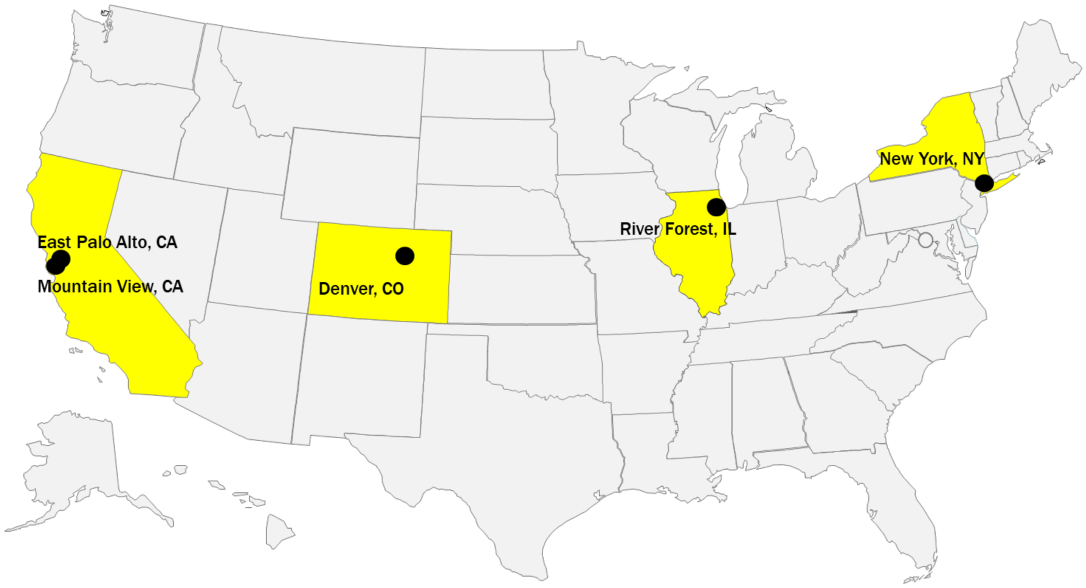

Figure 11: Locations for existing building electrification case studies

8.1 Forum Apartments

Denver, CO

Owned and Operated by the Colorado Coalition for the Homeless (CCH)

Building activity: Multifamily apartment with 100 studio units as well as a community room, computer lab, common kitchen area, and laundry facilities

Building age: Over 25 years old

Size: 49,791 square feet

Number of floors: 10 above grade, 1 below

Website: Forum Apartments

Source: Colorado Coalition for the Homeless

Project Summary

This Denver apartment building aimed to reduce its dependency on an unreliable district steam system and provide a more comfortable solution for tenants. PTHPs have been installed in each unit for space heating and cooling needs, and central electric water heaters provide domestic hot water. This project is expected to save $16,700 annually in energy costs and reduce the building's carbon emissions.

Project Timeline

Feasibility studies began in 2020, with construction beginning in 2022 and completed in 2023.

Electric Design Strategy

Old System	New System	Other Alternatives Considered
• Hydronic baseboards provided heating in each unit, using hot water generated from heat exchangers using steam from the local district heating utility • Window air conditioners provided cooling • Central air handling unit (AHU) with direct expansion (DX) cooling and hot water heating provided fresh air to common areas • Steam heat exchanger was used to generate domestic hot water from district heating utility	• PTHPs for space heating and cooling in units • VTHPs for space heating and cooling in corridors • Central electric resistance water heaters for domestic hot water • Packaged heat pump replacing the rooftop AHU	• PTACs with electric boilers, maintaining use of existing hydronic baseboards • PTACs with electric baseboard heaters • Heat pump water heaters

Project Motivations

- Desire to move away from an unreliable district heating system supplying heat to the building.
- Improving tenant comfort, as existing tenants and full-time employees reported insufficient cooling and unreliable heating in the building.
- Improved sustainability through an all-electric design to reduce carbon emissions.
- Operating cost reduction by separating from district heating system, which saw significant annual rate increases in recent years.

Financial Data

Project Cost:
~ $1,320,000 for all HVAC and electrification work ($13,200 per unit)

Estimated Annual Energy Cost Savings:
$16,700

Additional Savings:
Significant savings expected from building maintenance

Grants:
$932,000 provided by the Denver Office of Climate Action, Sustainability, and Resiliency

Credits:
4% low-income housing tax credit award from CHFA

Lessons Learned

Having an onboard design engineer during the conceptual phase of the project was invaluable to the CCH team. The engineer was able to provide real-life, actionable recommendations that allowed the project to move forward at a quicker pace than if a design firm had been brought on later.

Consider polling residents and maintenance staff to understand their wants and needs for a comfortable living environment. Initially, upgrading the cooling systems within the units was not a part of the scope of work. After speaking with residents and maintenance staff, however, a plan was put in place to replace the existing window PTAC units with new, high-efficiency PTHPs to provide a more comfortable living environment for residents.

An in-depth assessment of the building's electrical system was required to determine what upgrades would be needed to make the building all-electric. Initially, upgrading the electrical system throughout the building was not within the scope of the project, but it was later added to the project. This included upgrades to the panels serving each residential unit.

Key Project Stakeholders

- **Group14 Engineering**: Performed the energy study and serves as the commissioning agent.
- **Givens and Associates:** Designed the MEP upgrades.
- **Centerre**: Served as the installing contractor.
- **Colorado Housing and Finance Authority (CHFA)**: Provided a 4% low-income housing tax credit award, as part of the modernization rehab of the building. The

CHFA Qualified Allocation Plan established GHG reduction and electrification as guiding principles for the award of tax credits in 2021.

- Denver Office of Climate Action, Sustainability, and Resiliency: Provided a $932,000 grant to support the electrification.

8.2 Cook County Forest Preserves General Headquarters

River Forest, IL

Owned and Operated by Cook County Forest Preserves

Building activity: Office space, including private offices, conference rooms, and public meeting spaces

Building age: Built in 1931, expanded during the 1950s and again in 2016

Size: 23,200 square feet

Number of floors: 3

Source: [Forest Preserves of Cook County]

Project Summary

The building owners wanted to replace multiple aging space conditioning systems in different zones of the building with one new integrated system. The solution is a VRF system to provide the space heating and cooling needs throughout the building, and the renovation is expected to reduce the building's HVAC energy consumption by 83%.

Project Timeline

Design was started in late 2021 and finished in early 2022. The HVAC construction has not started due to delays in non-HVAC-related renovation. Construction went out for bid in 2022 and is expected to be completed in 2024.

Electric Design Strategy

Old System	New System

• East and west wings use natural gas boilers with associated radiators, with the west distributing steam and the east distributing hot water
  ○ Window ACs are used for cooling in both wings
• Vestibule wing is heated by a natural gas-fired packaged RTU and DX cooling
• Executive suite is served by residential-style natural gas furnaces and split-system AC
• Vestibule wing and executive suite are mechanically ventilated
	• A VRF system will be installed for both space heating and cooling, including:
	  ○ 5 VRF air-cooled condensing units
	  ○ 38 VRF indoor units
	  ○ 11 branch controllers
	  ○ 1 main controller
	  ○ 7 ERV units

Project Motivation

- Aging systems required extensive and frequent maintenance.
- Facility managers had to maintain multiple system types and designs in different parts of the building.

Financial Data

Project Cost:
~ $1,500,000 for all HVAC-related work

Incentives:
ComEd provided a financial incentive.

Energy Impacts

	Gas (therms)	Electricity (kWh)	HVAC EUI	Whole-Building EUI
Old System	22,780	194,857	105.1	117.7
New System	66	223,355	18.1	30.7
Savings	22,714	-28,498	87.0	87.0
Savings %	100%	-15%	83%	74%

Construction Specifics

- The project has a number of challenges, mainly sourced from the building age and the difference in construction date for different parts of the building.
- The building has multiple different types of existing HVAC systems.
- Additions to the original building are not at the same height as the original, making it difficult to connect it all together in a new system.
- New wiring was needed to extend power to serve the VRFs and ERVs, but the building had sufficient electrical capacity to service the new heating demands.
- Planned efficiency measures, including glazing improvements and air-sealing work, are also included, which probably account for less than 10% of the EUI reduction.

Key Project Stakeholders

- **Interface Engineering**: Designed the HVAC retrofit.
- **ComEd**: Provided a financial incentive through its emerging technologies program.
- **Institute for Market Transformation**: ComEd's contractor, provided technical assistance to interface to ensure the design met the very high efficiency HVAC specifications, which was a requirement for receiving the incentives.
- **Slipstream**: Providing M&V work for the project.

8.3 Early 20th Century Manhattan Multifamily Building

New York, NY

Building is owned in a co-op, where each tenant owns a share of the building.

Daikin prepared an online video (here), which describes the project and tenant experiences.

Building activity: Multifamily building (10 units)

Building age: Constructed in 1926

Size: 9,690 square feet

Number of floors: 5, plus a basement

Image Provided by Daikin

Project Summary

This project involved a change of space heating system design from a central oil-fired steam boiler to ductless multi-split heat pumps. The heat pumps also provide cooling as a replacement for window ACs. This renovation was completed with the main goal of improving building comfort, while also reducing environmental impact and energy costs.

Project Timeline

Project investigation and design occurred in 2019, with construction/installation starting in July 2020. Heat pump installation was completed in August 2020. Additional insulation and air-sealing work continued into February 2022.

Electric Design Strategy

Old System	New System	Alternatives Considered
• Oil-fired steam boiler with single pipe for distribution to radiators for space heating • Resident-owned window ACs for cooling • Tankless coil in the boiler provided domestic hot water off the oil-fired steam boiler	• Ten 3-ton, four-port multi-split ductless cold-climate ASHPs, which provide both space heating and cooling ○ Oil-heating system is now completely unused for space heating • Domestic hot water is unchanged, but may be electrified in the future	• VRF was considered but rejected, as its energy consumption would remain on the common electric account and then the co-op would have to bill each tenant for usage

Construction Specifics

- Insulation and air sealing were done first.
- Electrical upgrades were installed to accommodate heat pumps.
- Ten heat pumps were installed while the building was occupied.
    - Outdoor units were installed on the roof, back, and side of the building.
    - Indoor units were installed in each apartment.
    - Refrigerant lines were installed through the building.

Energy and Emissions Data

Performance:
Heating seasonal COP of 3.3 validated in cold conditions compared to a typical oil boiler with 80–95% efficiency

Emissions savings:
Reduced GHG emissions by 58% for HVAC + DHW and by 48% for the whole building

Project Motivations

- Improving comfort for the tenants.
- Reducing the building's environmental impact.
- Reducing energy costs.

Project Challenges

- Running refrigerant lines through a nearly 100-year-old building introduced many challenges.
- Placing the equipment (both indoor and outdoor units) required careful attention.

Financial Data

Project Cost:
~ $165,000 for heat pump installation, including minor electrical upgrades
~ $20,000 for insulation and air sealing
~ $18,500 total per unit

Estimated Annual Energy Cost Savings:
$1,226 per year, which entails a 10.3% reduction in HVAC + DHW energy costs, or 6% of overall building energy costs

Rebates:
~ $70,000 from Con Ed

Lessons Learned

- Equipment selection to ensure full heating electrification was a key priority.
- Odd electrical issues were uncovered, which required fixing a wiring issue under the street.
- Significantly more wall cutting was needed than initially expected. Also, significantly more soffits were needed to hide refrigerant lines than originally expected.
- Heat pump outdoor units can be installed in many locations, even in space-constrained projects.

- To maintain comfort in every space with ductless heat pumps, you do not need to install an indoor console in each room. Rather, the heating/cooling moves around the apartment as long as doors are generally open.
- Creative condensate management approaches were considered.
- The oil boiler is still used for domestic hot water production. Because it is so lightly loaded, it is operating very inefficiently and costing the building a lot of money (approximately twice what it was before the heat pump installation). For projects like these, it likely makes sense to decommission the boiler entirely and retrofit domestic hot water production to a heat pump at the same time as the space heating system.
- Consider unintended consequences. For example, the first-floor residents complain of cold floors now. This is likely caused by the fact that lots of excess heat was given off by the boiler in the winter; however, the boiler is no longer working to provide heat, thus the floor is now cold.

Key Project Stakeholders

- **Taitem Engineering**: Served as the primary engineer, provided the M&V of heat pump performance, energy savings, and cost savings.
- **Green Team LI**: Served as the mechanical contractor.
- **NYC Accelerator:** Worked with the building initially to evaluate their options.
- **Daikin**: Provided financial support to the building to complete the project.
- **Mr. Tom Sahagian**: Served as the project consultant/owners' representative.
- **Cornell University:** Conducting a comfort study.
- **Con Ed**: Provided a rebate through their Clean Heat Program.
- **NYSERDA**: Provided a grant for the M&V study.

8.4 East Palo Alto Government Center

East Palo Alto, CA

Owned by the County of San Mateo

Building activity: Offices and library

Building age: 48 years old

Size: 50,000 square feet

Number of floors: 3

Project Description: Taylor Engineers provided a description **here**

Source: taylorerg.egnyte.com/dl/V1XOYws7i3.

Project Summary

This project was initiated with the goal of replacing an aging natural gas boiler and domestic water heater with more sustainable solutions. An all-electric design was selected with two A2W heat pumps and a heat pump water heater. Significant energy savings are expected once the project is completed in the near future.

Project Timeline

The project was initiated in 2020.

Electric Design Strategy

Old System	New System
• Natural gas hot water boiler serving VAV reheat terminal units • A built-up air-handling unit served by a water-cooled chilled water plant • Natural gas-fired domestic water heater	• Two all-electric A2W heat pumps provide central chilled water and hot water heating • One heat pump operates with four-pipe heat recovery (can simultaneously supply and return hot and chilled water), and the other operates with two-pipe changeover configuration (can supply both hot and chilled water, but not simultaneously) • Heat pump water heater replaced natural gas-fired water heater

Project Motivations

- Aging existing systems required replacement, which allowed consideration for a range of all-electric new technologies.
- Sustainability goals drove interest in all-electric HVAC and domestic hot water systems.

Financial and Performance Data

Project Cost:
~ $10,000,000

Expected Energy and Performance:
Although energy analysis was not included in the project scope, significant energy savings are estimated due to best-in-class control sequences of operations following ASHRAE Guideline 36 (High-Performance Sequences of Operation for HVAC Systems).

Lessons Learned

- Water storage (buffer tank) is needed in the event of quick changes to building temperature settings, and this can be a structural challenge to fit on existing rooftops.
- Low hot water supply temperatures may require upsized terminal units, which may significantly increase project scope if terminal units are not planned to be replaced.
- Simultaneous heating and cooling loads in existing buildings may be more significant than new-construction buildings due to less efficient envelopes, which may make four-pipe heat recovery heat pumps more advantageous for retrofit applications.

Key Project Stakeholders

- **Swatt Miers Architects and Taylor Engineering**: Completed the mechanical and plumbing design.
- The job is currently out to bid, so a general contractor has not been selected yet.

8.5 Northern California Office Building

Confidential organization

Mountain View, CA

Building activity: Office

Building age: 25 years old (1997)

Size: 125,000 square feet

Number of floors: 5

Project Summary

The building owners wanted to replace an aging natural gas boiler with an electrified solution. An A2W heat pump was selected as the appropriate strategy. The team experimented with changes to hot water distribution temperatures to verify heating performance and inform hydronic heat pump design and selection.

Project Timeline

The project initiated in 2020 and was commissioned and turned over to the owner in February 2022.

Electric Design Strategy

Old System	New System
• Natural gas hot water boilers serving VAV reheat terminal units provide heating • DX packaged AC units provided cooling	• A2W heat pump providing hot water for heating • DX package AC units continue to provide cooling

Construction Specifics

- Project included electrical infrastructure upgrades.
- Lower water distribution temperatures were a concern.

Project Motivations

- Focus was to replace the system due to its age (original system was 25 years old).
- Aimed to provide an all-electric design.

Energy and Performance

- Energy savings are expected due to the high-performance sequence of operations similar to ASHRAE Guideline 36-2021.[21]

Lessons Learned

- The heat pump provided for this job was a new product for this manufacturer and experienced some issues due to a faulty manufacturer design, leading to leaking refrigerant. The manufacturer fixed the issue, but the issue resulted in a delay in reliable operation of 2–3 months.
- If owners/operators are uncertain about low hot water supply temperatures, tests can sometimes be done to verify heating performance by lowering the set point and seeing how long the building takes to warm up.

Key Project Stakeholders

- **Taylor Engineering:** Provided a basis of design narrative to be used as bridging documents.
- **Silicon Valley Mechanical**: Served as design and building contractor.
- **Novo Construction**: Served as general contractor.

[21]American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *ASHRAE Guideline 36-2021: High-Performance Sequences of Operation for HVAC Systems.* webstore.ansi.org/standards/ashrae/ashraeguideline362021.

Appendix

Emerging Technologies and RD&D Needs

The following research, design, and development (RD&D) needs were cited from industry stakeholder feedback and interviews as opportunities to accelerate the adoption of electric technologies to replace fuel-fired boiler systems.

- **Improved A2W Heat Pumps**: Research on achieving higher-temperature water and higher capacity from HPs was cited as a key need for greater electrification. Improving A2W heat pumps is an area that stakeholders felt would be beneficial for adopting the electric technology, particularly the ability to reach higher hot water temperatures closer to 180°F. Many larger commercial buildings are designed to operate using 180° water, which could be difficult to achieve using HPs, especially in cold climates on peak load days. Additionally, making these HPs smaller and more efficient would contribute to their increased adoption and open the door for the use of HPs for more projects.
- **Case Studies and Performance Data**: Another area stakeholders felt would help make electrifying their boiler systems more attainable is the development of more case studies and data. Specifically, there needs to be data and case studies for the various climate regions. Building owners need more detailed examples of how to implement these technologies within their own climate zones because implementation, feasibility, and costs vary across the different regions. Currently, there are limited case studies and examples of successful boiler retrofits in colder climates, because the majority of available studies are either in warmer climates, where the infrastructure is more suitable for electric technologies, or in California and New York, where aggressive emissions reduction goals have been set.
- **Workforce Development**: Contractors and installers are not as comfortable installing CCHPs and other electric heating technologies as they are with installing traditional technologies, so they are not advocating for electric retrofits. Workforce training would help the equipment installers become more comfortable and make it more probable that they would advocate for electric retrofits.
- **Grid-Interactive Controls**: Controls are becoming a more integrated part in decarbonization efforts. Research on how controls and grid-interactive efficient buildings (GEBs) can be utilized to shed and shift load to help offset and balance the hot water system consumption. GEBs utilize energy management systems to automatically reduce energy use during peak grid demand. More exploration on how these technologies can be integrated into hot water systems will help achieve greater adoption.

- **Hybrid VRF Solutions**: Research and development on hybrid VRF systems will also help electrify buildings. A two-pipe heat recovery VRF system is one technology solution that operates as a hybrid between a VRF and an A2W heat pump system. This involves substituting the refrigerant that would typically be distributed throughout the building in a VRF system with water. This technology maintains the advantages of a VRF system while reducing the large amount of refrigerant flowing through the building. This can also reduce the cost associated with a VRF system by minimizing the need for expensive and ongoing refrigerant leak detection servicing.

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For more information, visit: energy.gov/eere/buildings/

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