Decarbonizing Space Heating in Existing Centrally Heated Multifamily Buildings

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July 2025
Research Report

ACEEE

About ACEEE

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Acknowledgments

This report was made possible through the generous support of AO Smith, Commonwealth Edison, Consolidated Edison, Eversource, Los Angeles Department of Water and Power, National Grid, and United Illuminating. The authors gratefully acknowledge external reviewers, internal reviewers, colleagues, and sponsors who supported this report. External expert reviewers included Bill Lyons, Elevate Energy; Amit Kulkarni and Prathamesh Patil of Eversource; Jason Wexler, Gradient; Jordan Dentz, MaGrann Associates; Jordan Bonomo, New York City Housing Authority; and Adam Hinge from Sustainable Energy Partnerships. Internal reviewers were Mark Kresowik, Matt Malinowski, Michael Waite, and Mariel Wolfson. The authors also gratefully acknowledge the assistance of Asit Patel at ANP Energy, Ian Shapiro at Taitem Engineering, and Mark Zuluaga of Cadence OneFive. External review and support do not imply affiliation or endorsement. Last, we would like to thank the following members of ACEEE's editorial and communications team: Mary Robert Carter, Lynn DeRocco, Kate Doughty, Rob Kerns, Nick Roper, Mark Rodeffer, Ethan Taylor, Roxanna Usher, Keri Lee, and Mariel Wolfson.

Suggested citation

Nadel, Steven, Elizabeth Traynor, and Skye Gruen. 2025. *Decarbonizing Space Heating in Existing Centrally Heated Multifamily Buildings*. Washington, DC: ACEEE. www.aceee.org/research-report/b2506.

Data and licensing information

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Executive summary

Key findings

- Dozens of successfully completed projects, including some of the case studies noted in this report, indicate that many existing centrally heated multifamily buildings can be converted to heat pumps.
- Our analysis of space heating decarbonization options for centrally heated multifamily buildings finds that window heat pumps generally have the lowest life-cycle capital and energy costs (average of about $14,500 per apartment).
- Other heat pump options with somewhat higher life-cycle costs (average of $22,000–24,500 per apartment) are central air-to-water heat pumps and mini-split heat pumps. The window heat pumps, central air-to-water heat pumps, and mono-block heat pumps (a variation on mini-splits) are all relatively new to the multifamily market.
- Variable refrigerant flow (VRF) systems generally have substantially higher life-cycle costs, averaging over $30,000 per apartment.
- Another option is to use biofuels in existing or new boilers. This is only partial decarbonization as biofuels still have substantial carbon emissions. Also, biofuel supplies are limited. Life-cycle costs for burning biomethane with moderate distribution costs and for burning a drop-in bio-based fuel oil are higher than for window heat pumps but less than for mini-split heat pumps. But if gas distribution costs are high, biomethane has higher life-cycle costs than all but VRF systems.
- The heat pump systems we examined have high capital costs, at nearly $7,000 more per apartment than a replacement boiler plus window air conditioners. Operating costs, for both the window and mini-split heat pumps for space heating, are on average lower than for existing fossil fuel systems and thus these systems can be attractive to building owners if we can address the higher capital costs.
- Program and policy options to improve decarbonization economics include heat pump electric rates based on the cost of service, putting a price on carbon emissions, incentive and financing programs (potentially financed with carbon price revenues), emissions standards for new equipment, and continued research and development to reduce heat pump system installed costs.
- Other near-term steps include expanding training for contractors and building maintenance staff on best practice installation and repair techniques, and additional demonstration programs to further identify best practices.

Introduction

Much of the attention on decarbonizing residential space and water heating has been on single-family and town-home residences, where each home or apartment is served by its own heating system and water heater. Existing multifamily buildings with centralized heat systems will generally be harder to decarbonize. In the United States, there are about 23 million apartments in multifamily buildings containing five or more apartments, which is about 18% of all housing units. About 36% of these have central heating (EIA 2023a). Furthermore, a substantial proportion of low and moderate income (LMI) households live in these apartments, and thus decarbonizing these apartments is important for both emissions reduction and equity reasons.

Analysis and results

This report examines several options for decarbonizing space heating in centrally heated multifamily buildings. Existing buildings present a distinct challenge due to the need to work around existing structures and tenants. By contrast, it is much easier to design new multifamily buildings to run on heat pumps because such buildings can be designed with the necessary space, with an optimal distribution system, and with high-efficiency envelopes that reduce heating loads.

This report is intended for program implementers, state and local policymakers, community-based organizations, and other advocates as they work to decarbonize multifamily buildings. This report also provides insights for engineers and contractors working in these buildings.

For each option,[1] the full report discusses the technology, costs, performance, experience to date, strengths, weaknesses, and key takeaways.

We conduct an economic analysis for five types of space heating systems: mini-split heat pumps, window heat pumps, central air-to-water heat pumps, variable refrigerant flow heat pumps, and condensing boilers burning biofuels (this last option reduces but does not eliminate carbon emissions). Our economic analysis includes capital and energy costs over the 24-year average lifespan of a typical multifamily boiler or chiller. We examine each decarbonization option for 533 apartments that are included in a representative sample of U.S. homes and apartments from the 2020 Residential Energy Consumption Survey (RECS) published by the Energy Information Administration.

Average capital and operating costs,[2] seasonal efficiency, and life-cycle cost (capital plus energy) for the five systems we examined in our economic analysis are summarized in table ES1. Average operating and capital costs are also illustrated in **Figure ES1**. Our analysis indicates that window heat pumps on average have the lowest life-cycle costs of the heat pump options followed by central air-to-water heat pumps and mini-split heat pumps. These three options should be considered the primary choices for decarbonizing centrally heated multifamily buildings. Variable refrigerant flow (VRF) systems generally have higher life-cycle costs.

Another option is to partially decarbonize using biofuels burned in high-efficiency boilers. Life-cycle costs for these options are greater than window heat pumps but less than mini-splits when burning biomethane with moderate distribution costs or drop-in bio-based fuel oil. But if gas distribution costs are high, biomethane has higher life-cycle costs than all but VRF systems.

We also conducted a variety of sensitivity analyses, which are discussed in the main report.

[1] The five discussed in the next paragraph plus packaged terminal heat pumps, heat recovery chillers, and geothermal heat pumps. These last three options are discussed in the text for reasons discussed in the main report.

[2] We include capital costs for heating and cooling but only operating costs for heating since many buildings do not presently have cooling.

Table ES1. Midpoint cost and efficiency estimates and life-cycle costs for different system types

System type	Midpoint installed cost/apt.	Avg. seasonal COP	Avg. life-cycle cost
Window heat pumps	9,300*	2.56	$14,474
Oil boiler burning drop-in bio-oil	1,377**	0.87***	20,831
Central air-to-water heat pump with electric resistance backup	13,964**	2.32***	21,898
Central air-to-water heat pump with gas utility biomethane backup	14,568**	2.52***	22,315
Central air-to-water heat pump with renewable propane backup	15,016**	2.52***	22,665
Condensing gas boiler burning biomethane	1,209**	0.90***	22,902
Mini-splits	$16,435*	2.40	24,563
VRF	20,379*	1.60	31,581

* These are costs for the initial system including average costs for upgrading onsite electric systems. For these systems our analysis also includes a discounted cost for a replacement system in year 16 using a 5% discount rate. For biomethane we only show the moderate gas distribution cost scenario here; the full report also includes a high gas distribution cost scenario.

**For these systems we add $1,297 for three window air conditioners (less for small apartments, more for large apartments) since unlike the other systems, these systems usually need a separate system for cooling. We assume these air conditioners need to be replaced every 10 years; the initial and replacement costs (using a 5% discount rate) are included in the life-cycle cost.

**Seasonal coefficient of performance (COP) is just for the boiler or heat pump and does not include losses in the distribution system, which we include in the analysis separately. Seasonal COP is generally based on field performance.

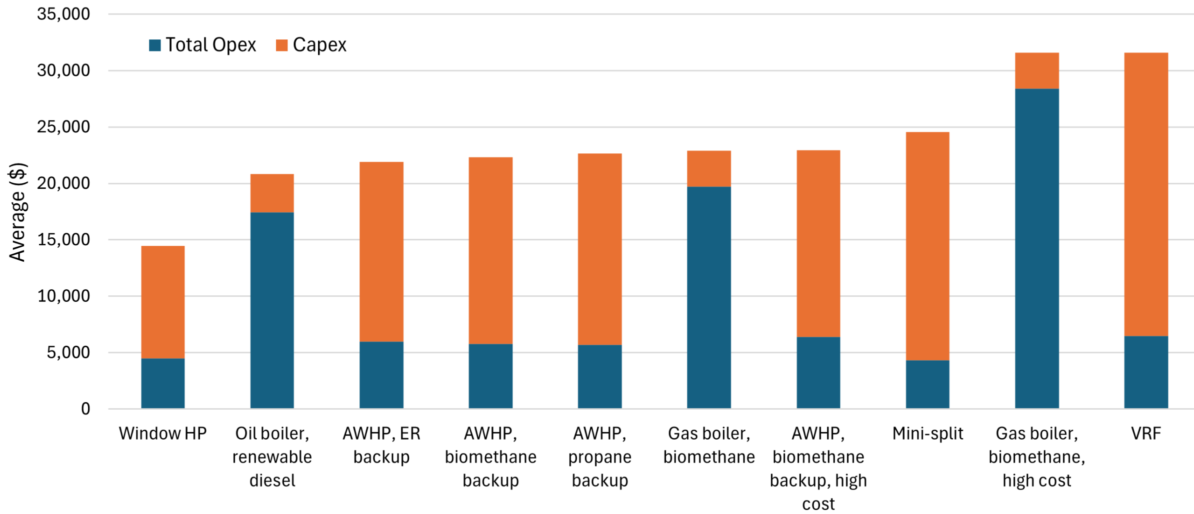

Figure ES1. Average operating cost (opex), capital costs (capex), and life-cycle costs (LCC) over the 24-year study period for decarbonization options

Building-specific issues will determine which system options make sense in a particular building. Table ES2 summarizes the limitations and strengths of each option, including the types of buildings where they may, or may not, be appropriate.

Table ES2. Limitations and strengths of the options

System type	Limitations	Strengths
Mini-split heat pumps	Can be difficult to install in high-rise buildings, but new systems can be installed from the inside; could change who pays for heat.	Medium-cost system suitable for most buildings.
Window heat pumps	Designed for single-hung and double-hung windows, current products often do not fit in other windows. Exterior aesthetics may not be appropriate for some buildings. They could change who pays for heat.	Generally lowest cost of the heat pump options analyzed.
Packaged terminal heat pumps (PTHP)	Very difficult to install in apartments that do not presently use packaged terminal air conditioners could change who pays for heat. High-efficiency systems being developed but not presently available.	A good option for apartments now using packaged terminal air conditioners.
VRF systems	Can be difficult to install and operate in existing buildings and as a result tend to have high cost and lower efficiency.	Can serve several apartments with one system; generally does not change who pays for heat.
Condensing boilers using alternative fuels	Alternative fuels are expensive. Such fuels reduce carbon emissions, but substantial emissions remain. Heat distribution system has significant heat losses. This	Can use existing boiler, resulting in low capital cost; does not change who pays for heat.

System type	Limitations	Strengths
	option provides only space heat; a separate system is needed for cooling.	
Central air-to-water heat pump	These systems are only for buildings with hot-water distribution, not for those using steam distribution. Some existing buildings may not have space for these systems. They often need a backup heating system for cold days. The heat distribution system has significant heat losses. Unless there is a central cooling system (not very common in multifamily), this option provides only space heat; a separate system is needed for cooling (our analysis assumes room air conditioners, although adding fan coils to provide cooling from the heat pumps is a more efficient but higher capital cost option).	Medium cost; does not change who pays for heat.
Heat recovery chillers	A subset of the above, these systems need a significant source of heat, which is generally not available in multifamily buildings.	High efficiency; heat recovery often allows using smaller systems.
Ground-source heat pumps	Most expensive of the systems examined and only suitable for some sites.	High efficiency.

We also examined the economics of combining energy efficiency upgrades with decarbonization and find that a multifamily building energy efficiency package will provide substantial net benefits for the alternative fuel options, moderate net benefits for the VRF option, and smaller benefits for the other electrification options due to the modest energy use per apartment prior to energy efficiency. However, energy efficiency has additional benefits such as reducing peak winter electricity demand (much of the United States is likely to become winter peaking in the next decade or two), improving occupant comfort, and reducing the need for a backup source of heat that may not be fully reflected in our economic analysis. For this reason, many multifamily decarbonization practitioners and some policymakers strongly recommend improving a building's energy efficiency as part of a decarbonization project.

Discussion and recommendations

Each building will have unique opportunities, but our analysis indicates a potential order in which options might be investigated. In most cases, the three heat pump options with the lowest life-cycle costs (window, mini-split, and central air-to-water heat pumps) should be considered, with the best choice often based on building-specific characteristics.

While dozens of buildings have been converted, the economics are challenging due to the high capital costs of heat pumps relative to a replacement boiler. If we can address heat pump capital costs, on average both the window and mini-split heat pumps have lower operating costs for space heating than existing fossil fuel systems. Moreover, if a building lacks air-conditioning, sometimes a heat pump can be installed instead of an air conditioner at low incremental cost.

One way to manage costs is partial decarbonization: installing new heat pumps to serve much of a building's heat need, but having a backup system that kicks in on very cold days. Often an existing boiler can be used as the backup, providing time for weatherization improvements to be implemented and improved cold climate heat pumps and backup systems to be developed, allowing large boilers to be retired later.

Program and policy options to spur decarbonization could help overcome the economic and other barriers. Options to consider include heat pump electric rates based on the cost of service, putting a price on carbon emissions, incentive and financing programs (potentially financed with carbon price revenues), identifying and addressing code barriers, and continued research and development to reduce heat pump system installed costs. Who pays for heat following decarbonization is also an important issue for many tenants, landlords, and policymakers, particularly for affordable housing; we discuss this issue in the main report.

Other necessary near-term steps are expanding efforts to train contractors and building maintenance staff on best practice installation and repair techniques, and additional demonstration programs to further identify best practices. Due to the limited experience to date, demonstration programs should particularly target window heat pumps, central air-to-water heat pumps, and mono-block mini-systems that do not need to be hung on exterior walls.

Existing multifamily buildings can be decarbonized, contributing to reduced emissions and efforts to slow climate change. There has been substantial progress in recent years in improving system options, developing new approaches (e.g., window and mono-block heat pumps and central air-to-water heat pumps), and learning what works on the ground. These efforts should be accelerated, building on our findings that these new systems on average will generally have lower life-cycle costs than other decarbonization options.

Introduction

Much of the attention on electrifying residential space and water heating has been on single-family and town-home residences where each home or apartment is served by its own heating system and water heater. Existing multifamily buildings with centralized heat systems will generally be harder to decarbonize, because new systems can be hard to retrofit in old buildings, and because existing buildings are generally occupied, making construction work more difficult. This report looks at options for decarbonizing these centrally heated multifamily buildings (defined as buildings with at least five apartments).

According to the Energy Information Administration (EIA) *2020 Residential Energy Consumption Survey* (RECS), there are about 23 million apartments in multifamily buildings containing 5 or more apartments, which is about 18% of all housing units (EIA 2023a). Furthermore, a substantial proportion of low and moderate income (LMI) households live in these apartments,[3] and thus decarbonizing these apartments is important for both emissions reduction and equity reasons.

A 2022 ACEEE report (Nadel and Fadali 2022) looked at installing variable refrigerant flow (VRF) and ductless mini-split heat pumps in high-rise multifamily buildings and found the economics challenging. Fortunately, several new heat pump systems developed for commercial buildings provide additional options for decarbonizing multifamily buildings. Furthermore, the 2022 ACEEE report considered natural gas as the alternative to electric heat pumps, but if decarbonization is the goal, lower-carbon alternative fuels such as biofuels should be considered instead of natural gas.

This report examines ways these new systems can be applied to multifamily buildings and compares their economics to other decarbonization options such as use of biofuels or use of less centralized heat pumps such as VRF and mini-split systems. To do this we examine various decarbonization options for a representative sample of several hundred multifamily buildings with central heating across the U.S., with different configurations and climates, as documented in detail in the 2020 RECS. On average these apartments are small, averaging 868 sq. ft. in floor area (ACEEE analysis of data in EIA 2023a). We look at space heating in this report as a previous ACEEE report addressed water heating (Perry, Khanolkar, and Bastian 2021). We focus on existing buildings because they present a distinct challenge. By contrast, it is much easier to design new multifamily buildings to run on heat pumps because such buildings can be designed with space to accommodate heat pumps, with a distribution system optimized for heat pumps, and with high-efficiency envelopes that reduce heating loads.

Our goal for this project is to provide information to program implementers, state and local policymakers, community-based organizations, and other advocates to consider as they work to decarbonize multifamily buildings. These are the target audiences for the report. The project will also provide insights for engineers and contractors working in these buildings.

[3] For example, the National Multifamily Housing Council estimates that nearly 70% of apartment households have an annual income below $75,000. For all households (apartment and single-family), less than 50% of households have an income below $75,000 (NMHC 2024).

Multifamily apartments in the United States

The 2020 Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS) provides useful information characterizing multifamily apartments. We define these to be apartments in buildings with five or more apartments. Some key statistics (EIA 2023a):

- Of apartments in buildings with five or more units, 86% are rental units, with the remainder being owner occupied, such as condominiums and cooperatives.
- These units are of varying ages, with 18% built in the 1970s, 16% in the 1980s, 14% in the 2000s, 13% built before 1950, and the remaining 39% of units built in the 1950s, 1960s, and 2010s.
- The majority of these apartments (69%) have brick, concrete block, stone, or stucco walls, making it more difficult to drill through walls to install new systems.
- Apartments in buildings with five or more units are spread throughout the United States, with 34% in the South, 25% in the West, 22% in the Midwest, and 18% in the Northeast using EIA definitions of regions (these figures include both units with central heating and those with dedicated heating systems for each apartment).
- Of these apartments, 52% use natural gas for at least some energy uses while 29% do not have natural gas service in the neighborhood and the remaining 19% have gas available but do not use it.
- Of apartments with space heating, 60% use electricity for space heating, primarily electric resistance heat. But 23% of apartments with electricity as their primary heating source use heat pumps.[4]
- Of the apartments with space heating, 36% use natural gas as the primary source of heat, primarily central systems that serve more than one apartment, but 10% of apartments heated with gas use room heaters of some type. An analysis by SWA (2019) found that fossil fuel systems are more common in moderately and very cold climates, while electric systems are more common in milder climates.
- About 3% of these apartments heat with oil or propane.

The distribution of space heating systems and fuels for multifamily buildings (five units or more per building) is provided in figure 1, highlighting in blue the portion of the market that is analyzed in this report.

[4] While outside the scope of this report on buildings with central heating, the high proportion of buildings with electric resistance heat indicates a large opportunity to replace these electric resistance systems with heat pumps (e.g., see Nadel, Amann, and Chen 2024).

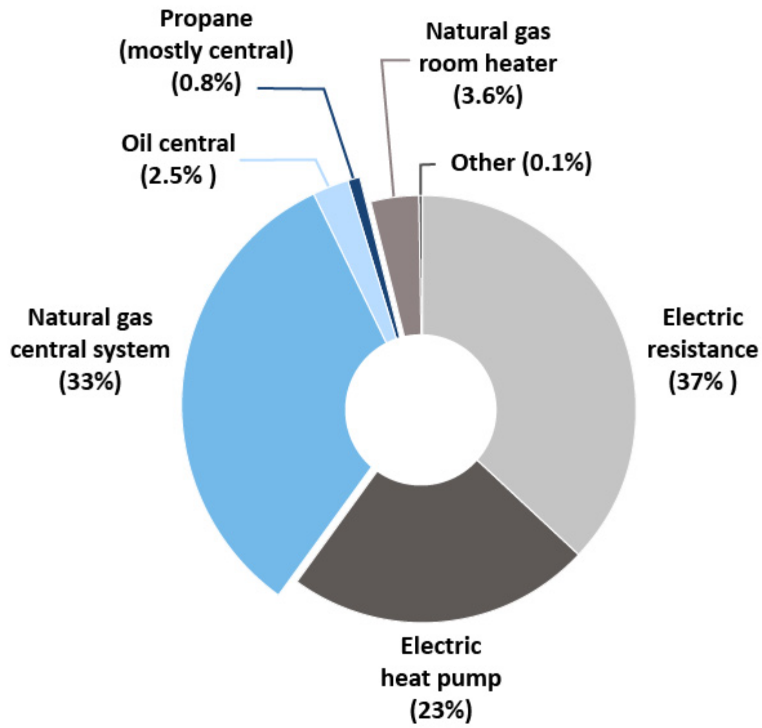

Figure 1. Typology of multifamily apartments (five units or more per building) including, in blue, the portions that are the focus of this report

The geographic distribution of multifamily apartments with central heating using fossil fuels (the blue portions in figure 1 above) is provided in figure 2, which shows that centrally heated multifamily buildings are particularly common in New York State, followed by Illinois, but with significant percentages also in California, Colorado, Maryland, Massachusetts, Minnesota, New Jersey, Ohio, and Pennsylvania.

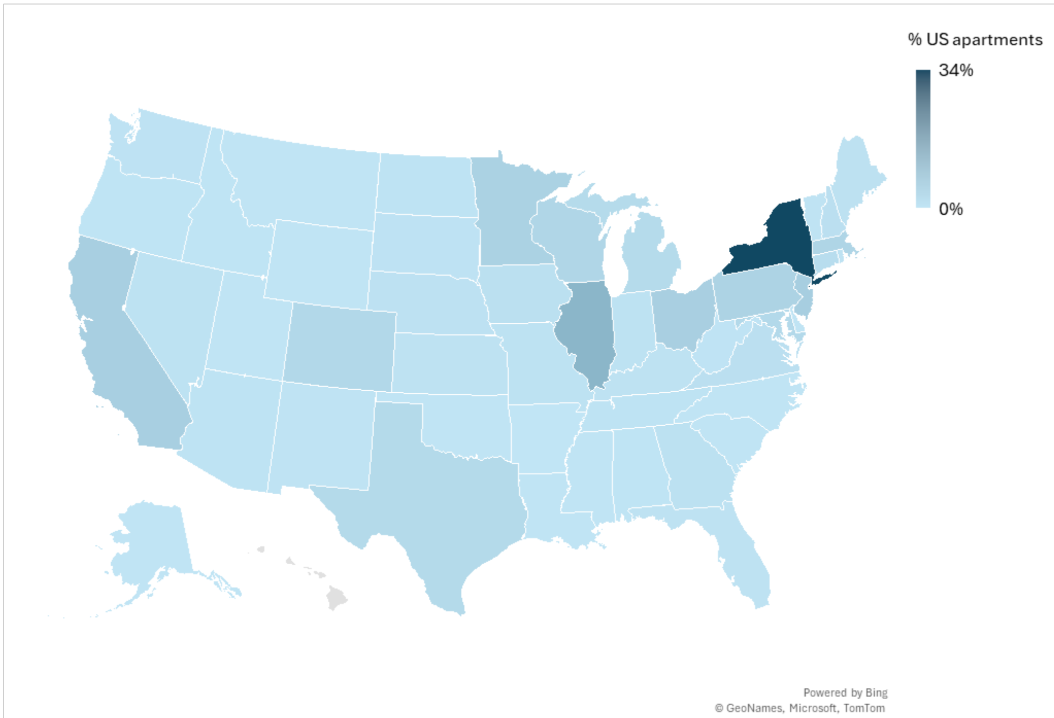

Figure 2. Proportion of multifamily apartments with central heating using fossil fuels in buildings with five or more units by state. Source: ACEEE analysis of RECS 2020 microdata, using RECS weighting factors.

One limitation of the RECS data for multifamily buildings is that it is based on a survey of tenants who often do not understand the specifics of different heating systems. According to this tenant survey, many tenants report having a central furnace that distributes warm air to multiple apartments. Our understanding, based on discussions with several experts, is that warm air systems serving five or more apartments are rare because such systems are complicated and may run afoul of local regulations that restrict sharing of air between apartments and/or that require individual thermostatic control in each apartment.[5] Therefore, for our analysis we assume that if a tenant reports that their heat comes from a system that heats more than one apartment, in most cases this means a central boiler that distributes hot water or steam to individual apartments. For hot-water systems, valves are commonly used to adjust the flow of hot water to individual apartments so that temperatures can be regulated at the apartment level (that is, when heat is needed the valves are opened, and when heat is not needed the valves are closed).

System options for decarbonization

This study focuses on space heating for existing multifamily apartments with central hot-water or steam heating systems that serve more than one apartment. Most commonly these apartments are now heated with a central gas- or oil-fired boiler that distributes hot water or steam to radiators or baseboard heaters in each apartment. In the sections below we discuss the following low-carbon options for heating these apartments:[6]

[5] There are exceptions to both of these provisions, particularly for old buildings that may be “grandfathered.”

[6] The order we present these sections is not a ranking; we explain the logic for this order later in this report.

1. Mini-split heat pumps
2. Window heat pumps
3. Packaged terminal heat pumps
4. Variable refrigerant flow (VRF) systems
5. Condensing boilers using alternative fuels
6. Heat pump chillers
7. Heat recovery chillers
8. Ground-source heat pumps

All but option 5 involve using various types of electric heat pump. For heat pumps to decarbonize space heating, electric generation needs to be decarbonized. About half of U.S. states are moving to a carbon-free or very low carbon electric grid (CESA 2025). The other half of states are also generally reducing emissions, but often more slowly, due to a decline in coal generation and increases in natural gas and renewable energy generation. Most alternative fuels, such as biofuels, do produce CO_2 when burned, but many of these are produced from biomass. Plants remove CO_2 from the atmosphere as they grow, making most biofuels a lower carbon option than fossil fuels, but depending on the source of biomass and the processing steps used, biofuel net emissions are generally greater than zero (Traynor and Waite 2025).

Not all of these system options will be appropriate for an individual building. Table 1 briefly summarizes the limitations and advantages of these systems, with further discussion and explanations in the sections that follow.

Table 1. Low-carbon options for space heating in multifamily buildings and their limitations and strengths

System type	Limitations	Strengths
Mini-split heat pumps	Can be difficult to install in high-rise buildings, but new systems can be installed from the inside; could change who pays for heat.	Medium-cost system suitable for most buildings.
Window heat pumps	Designed for single-hung and double-hung windows, current products often do not fit in other windows. Exterior aesthetics may not be appropriate for some buildings. They could change who pays for heat.	Generally lowest cost of heat pump options analyzed.
Packaged terminal heat pumps (PTHP)	Very difficult to install in apartments that do not presently use packaged terminal air conditioners; could change who pays for heat. High-efficiency systems being developed but not presently available.	A good option for apartments now using packaged terminal air conditioners.
Variable refrigerant flow (VRF) systems	These can be difficult to install and operate in existing buildings, and as a result tend to have high cost and lower efficiency.	Can serve several apartments with one system; generally does not change who pays for heat.

System type	Limitations	Strengths
Condensing boilers using alternative fuels	These are likely only for buildings currently heated by central hydronic systems. Alternative fuels are expensive. Such fuels reduce carbon emissions, but substantial emissions remain. Heat distribution system has significant heat losses. This option provides only space heat; a separate system is needed for cooling (in our analysis we assume room air conditioners).	Low capital cost as building already configured for a boiler; does not change who pays for heat.
Central air-to-water heat pumps (AWHPs)	This is only an option for buildings with central hot-water distribution systems, not for those using steam distribution. They often need a backup heating system for cold days. The heat distribution system has significant heat losses. Unless there is a central cooling system (not very common in multifamily), this option provides only space heat; a separate system is needed for cooling (our analysis assumes room air conditioners, although adding fan coils to provide cooling from the heat pumps is a more efficient but higher capital cost option).	Medium cost; does not change who pays for heat.
Heat recovery chillers	A subset of the above; needs significant source of heat (generally not available in multifamily buildings) or thermal storage; likely only for buildings with current central hydronic heating and cooling.	High efficiency; heat recovery often allows using smaller systems.
Ground-source heat pumps	Most expensive of the systems examined and only suitable for some sites.	High efficiency.

The order we present these sections is not a ranking—our comparative analysis begins on p. 38. In the sections below we describe each of the options. We begin with mini-splits because they are probably the most widespread and applicable. Window heat pumps, PTHP, and VRF follow because they are related to mini-splits in various ways. All of these are distributed systems, with multiple units to heat different rooms, apartments, or sections of a building. We then turn to whole building centralized systems: boilers, central air-to-water heat pumps, heat recovery chillers, and ground-source heat pumps.

Mini-split heat pumps

Key takeaways

- Mini-splits have lower upfront costs and can be less complex to install than central VRFs, a system type (discussed below) that they are often compared to.

- Field studies of completed retrofits report that while the systems save substantial amounts of energy, many perform below the rated efficiency.
- New products that can be installed from the inside, such as the Ephoca All-in One (AIO) Wall Mounted, are attractive options for mid- and high-rise multifamily buildings that further reduce installation complexity and have the potential for higher efficiency.

Introduction

Mini-split heat pumps (commonly referred to simply as "mini-splits") are an all-electric, ductless air-source heat pump (ASHP) technology used for decentralized heating and cooling.[7] They provide both heating and cooling, so any existing room air conditioners to be retired. They function by adding or removing heat to/from an indoor space via refrigerant lines connected to an outdoor compressor with a variable speed drive, allowing the system to modulate operation based on heating or cooling load. Depending on the heating and cooling needs of an apartment, there may be one or two outdoor units/condensers per apartment, with each condenser serving one or more indoor units/evaporators. Typically, one outdoor unit serves one to three rooms, but some manufacturers claim their condensers can serve as many as eight evaporators (although more units increase complexity and reduce efficiency). A typical unit is illustrated in figure 3.

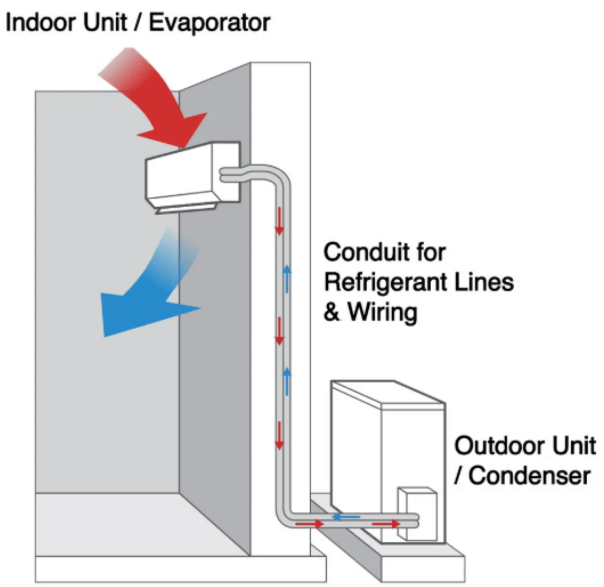

Figure 3. Schematic of a typical ductless mini-split. Source: Shawn Kresge Electric, Heating and AC Services.

Mini-splits are a more efficient alternative to electric resistance and other traditional heating, ventilating and air-conditioning (HVAC) systems. In multifamily retrofits, mini-splits have been found to be most

[7] We use the term "mini-split" broadly and include systems with more than one indoor unit (sometimes called "multi-splits," systems that make limited use of ducts), as well as single-package systems such as the Ephoca AIO that compete with true mini-splits.

cost effective for low/mid-rise buildings with high heating and cooling loads when replacing an existing system using electric resistance or a high-cost heating fuel (SWA 2019).

New system types that can be installed from the inside

Recently, a few units have become popular for medium-rise multifamily retrofits because they can be installed from the inside.[8]

In 2020, Ephoca launched the HPAC 2.0, a single-package system with no outdoor unit and no field refrigerant connections required. Two holes are required to the outside, as shown in figure 4. They also have kits to install a unit just below a window, also shown in figure 4. This unit, now called the AIO Wall-Mounted, offers greater design flexibility and is less invasive for retrofit applications. These systems come pre-charged and are less prone to refrigerant leaks. Ephoca is already an established brand in Europe and is gaining presence in the United States (HVACinformed 2020). Other manufacturers, such as Olimpia and Ice Air, have recently begun to sell similar systems.

Figure 4. Ephoca single-package system with conventional connections to the outside on the left, in a side-arm configuration in the middle and with an under-window application on the right. Source: Ephoca.

Availability

According to the 2020 Residential Energy Consumption Survey (RECS), approximately 310,000 mini-splits were utilized by apartments in buildings with five or more units (EIA 2023a). Industry sources wishing to remain anonymous estimated that a little more than 1.5 million mini-splits were sold in the United States in 2024, including both single and multifamily. The North American market is projected to grow at an annual rate of 4.8% between 2024 and 2032 (Dataintelo 2024). These growing sales are due in part to a desire to add air-conditioning to existing buildings, and in part to these units' high efficiency, potential for multizone heating and cooling, and quiet operation. Other factors include rising energy prices, the proliferation of incentives for heat pumps and electrification, and technical advances that bring costs down and improve energy performance, especially in cold climates (Global Market Insights 2024).

In an effort to expand the market to colder climates, many manufacturers have introduced cold climate mini-splits that are optimized for space heating rather than cooling loads, with the first product introduced in 2008 (U.S. Department of Energy 2012).

[8] Fujitsu now offers a split terminal heat pump (STHP) as an alternative to packaged terminal air conditioners (PTACs). While this unit is a mini-split, because it replaces PTACs we discuss it in the PTHP section later in this report.

Top mini-split manufacturers include Daikin, Fujitsu, LG, and Samsung. Major U.S. manufacturers such as Carrier and Trane also sell units, and Chinese-branded units are entering the U.S. market from such firms as Midea and Haier.

System costs

Cost estimates for mini-splits in multifamily apartments vary depending on location and complexity of installation. Many of the costs we obtained are from New York City (NYC), a very high-cost location.

The TECH Clean California program (2025) reports an average cost of $9,556 over several years (we estimate $9,771 in 2024$) per apartment. Most apartments used just one mini-split, and it is unclear how many of these units provide all heating and cooling for an apartment and how many apartments also have other heating or cooling systems. We increase this cost by 50% to assume that half the apartments need two outdoor units; this results in a cost of $14,657 per apartment.

One recent New York City source recommends a cost of $23,500 per apartment, plus $6,000 for electrical upgrades if the building was built before 1980. This estimate cites input from local contractors in NYC and assumes one outdoor unit and several indoor units per apartment (M. Zuluaga, cofounder and chief revenue officer, Cadence OneFive, pers. comm., January 2025). This is the highest of the estimates we obtained, as summarized in table 2.

Table 2. Examples of installed costs for mini-splits in multifamily buildings

Source/Case study	Installed cost per apartment (2024$)
TECH Clean California Program, 2025 (partial electrification as generally just one mini-split per apartment)	$9,771
Increase above by 50% for second outdoor unit needed in half of apts. for full electrification	$14,657
AEA Fujitsu units, NYC, 2025	$12,030
Steven Winter Associates, NYC, 2019	$15,420
Lyons, B., Chicago, 2025	$20,099*
AEA Ephoca units, NYC, 2025	$21,427
Decrease above by 15% to convert from NYC to national price as discussed in text	$18,213
Zuluaga, M., NYC, 2024	$27,500

Note: Pre-2024 costs were adjusted to 2024$ using the Federal Reserve Implicit Gross Domestic Product (GDP)Deflator. For Zuluaga we assume two-thirds of the apartments are old enough to need electric upgrades.

***The Chicago project includes an air handler and ducts, so while the project does involve mini-splits, they are not ductless.**

Many of these cost estimates are from NYC, a very expensive place for construction. In order to approximate a national average cost for multifamily buildings, we reduce NYC costs by 15% to approximate a national average for urban areas.[9] For our analysis we assume a cost of $16,435 per apartment. This is the average of the TECH Clean California Program plus 50% and the AEA Ephoca minus 15% estimates. The Ephoca is the second highest of our estimates and captures a system type that is growing in popularity for multifamily apartments.

Performance

Multiple studies of the field performance of mini-splits have emerged over the past five years. A meta study published by the Northwest Energy Efficiency Alliance (NEEA) in 2021 reviewed more than 25 sources evaluating the performance of mini-splits in residential buildings. The meta study concluded that while most of the studies reported energy savings over alternative heating systems, most installations underperformed relative to manufacturer data or engineering models. The underlying cause of this underperformance was found to be inattention to overall design, installation, and operations and maintenance factors that consider how a system interacts with its context and the building occupants (Trager et al. 2021). Similarly, Klint et al. (2024) also found that field performance is less than rated performance.

A study conducted by Cadmus to assess cold climate air-source heat pump (ccASHP) performance in one- to four-family homes in New York and Massachusetts reported an average seasonal heating performance of 2.34 COP.[10] Ductless single-zone systems performed more efficiently (average seasonal COP of 2.76) than multizone systems serving more than three indoor units (average seasonal COP of 1.32) (Cadmus Group 2022).

The New York State Energy Research and Development Authority (NYSERDA) and The Levy Partnership installed and monitored the performance of cold climate ASHPs in 20 one- to three-family buildings in New York State. The majority of these retrofits used ductless mini/multi-split systems. The data collected revealed an average COP of 2.4, or 80% of the manufacturer-rated Heating Season Performance Factor (HSPF) (NYSERDA 2022).

Taitem compared the performance of mini-splits in six multifamily buildings in New York to that of large VRFs in nine multifamily buildings in the same context and found that the VRFs used 77% more energy on average than the mini-splits (Taitem Engineering 2020).

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[9] RS Means (2021) reports a mechanical system cost multiplier of 1.297 for New York City and approximately 1.1 for Boston, Chicago, and California. Since multifamily building are more common in major cities, we use 1.1 for the national average and discount NYC costs by 15% to estimate a national average cost [(1.297 – 1.1)/1.297=15%). We use 2021 data because they are public; nonpublic 2024 data show a similar relationship.

[10] Coefficient of performance (COP) is the ratio of heat output from a system relative to the energy input into a system. Electric resistance heat has a COP of one. Most heat pumps have a COP greater than one because they extract heat from the ambient air or a water source. Seasonal COP is the average COP over the course of an entire heating season. The COP of a heat pump is higher in relatively warm weather (e.g., the 40s and 50s Fahrenheit) than in very cold weather (e.g., 5 ^{o}F). Seasonal COP uses an average of performance during different outdoor conditions.

A study of 15 mini-split systems in Massachusetts and Connecticut reported that COP varied between 1.6 and 2.3, with an average of 2.0. Note that these results were based on metered data during a cold spell in February of 2023 and are not weather normalized (Guidehouse, Inc. 2024).

A Minnesota study completed in 2024 evaluating cold climate mini-split heat pumps in three multifamily buildings reported COP ranging from 2.05–2.25 (Schoenbauer, Genty, and Haynor 2024).

In our analysis, we use the NYSERDA 2022 data as an average and note the Guidehouse 2024 data for cold climate performance.

Experience to date

Mini-splits have gained popularity in multifamily retrofit applications in the United States when replacing electric resistance baseboard heating and other outdated heating and cooling technology. They are cited as a high-efficiency alternative to other all-electric options and can be simpler to install than large VRFs while providing heating and cooling with greater comfort and control for tenants (Dentz, Podorson, and Varshney 2014). They have seen significant growth in recent years because of their low profile, adaptable modular construction, and suitability for homes in northern climates that have not had central cooling but increasingly need to due to climate change and urban heat islands.

While the market for mini-splits is more established in single-family homes, it is growing in multifamily retrofits. Still, the complexity and cost of installation, coupled with aesthetic concerns and metering considerations have resulted in a slower adoption of the technology in multifamily, especially high-rise (Urban Green Council 2020).

The District of Columbia Sustainable Energy Utility (DCSEU) worked with Paradise at Parkside, an affordable housing complex in Washington DC, to replace unitized gas and electric heating and cooling systems with mini-splits in 653 apartments in a phased retrofit project beginning in 2021. Since the renovation, building management and residents report lower utility bills, increased comfort, and fewer maintenance issues (DCSEU 2024).

Minnesota Center for Energy and Environment (CEE) installed and monitored ductless cold climate mini-splits in three multifamily buildings in Minnesota. The retrofit resulted in significant improvements in energy efficiency and operating costs at all sites. The mini-splits displaced 48–86% of the heating load previously met by electric resistance baseboards, while reducing more than 50% of the displaced energy. The installation faced challenges in integrating the mini-splits with the existing electric baseboards, which remained in place as a backup heating system. To address this, CEE recommends smart thermostats to ensure that the backup system turns on only when the heat pumps cannot meet the heating demand (Schoenbauer, Genty, and Haynor 2024).

In 2023 the Association for Energy Affordability (AEA) installed 192 Ephoca air-to-air heat pumps in a New York City Housing Authority (NYCHA) building with 65 apartments, replacing a two-pipe steam system. The heat pumps were installed in the existing air conditioner sleeves used for through-the-wall air conditioners or packaged terminal air conditioners (PTACs) but required significant aftermarket modifications, including installing a divider to separate air flows and an adapter to offset the unit from the existing convectors. This added significant time and cost to the installation (Asit Patel, ANP Energy Consulting Services Corp., pers. comm., January 2025). Monitoring of electricity use shows high-efficiency operation (COP in the 2.6–3.0 range). Residents and NYCHA report positive feedback on the units. There were operational issues on a few units initially, but these issues are now diminished (Shapiro 2024a).

In 2024 Design Build Detroit completed the retrofit of a 123-unit building using Ephoca single-package units, opting for the through-the-wall design over traditional mini-splits due to the building's height and lack of balconies, making it challenging to install condensers close to the apartments they served. Performance data are not yet available (Gigawatt 2025).

Strengths and weaknesses

Strengths

Mini-splits offer several advantages over alternatives for multifamily buildings: Mini-splits tend to be less expensive to install than VRFs, and have among the highest efficiency of the heat pump options and avoid the distribution losses of VRF and central heat pump chillers. The availability of mini-splits in small capacities makes them well suited for small, low-load apartment units (Dentz, Podorson, and Varshney 2014). Local contractors are also more likely to be trained to install them; this is especially important in nonurban areas (NYSERDA 2021).

Mini-splits can be easier to install in retrofit applications than other heat pump systems: While central VRF systems can use fewer outdoor units (with one outdoor unit serving more than one apartment), mini-split compressors are smaller, lighter, and lower profile. The outdoor units can therefore be stacked, clustered closer together, or hung from the building façade, ultimately taking up less space than VRF units (Shapiro 2024b).

Mini-splits require a lower refrigerant charge than central VRF systems with the same pipe lengths, by as much as 60% (Taitem Engineering 2020). Lower volume coupled with shorter, simpler refrigerant runs mean that leaks in mini-split systems are less hazardous and easier to locate and repair.

Because equipment is set up with one or a few systems per apartment, fewer residents lose heating or cooling during maintenance or system outages compared to a central system.

Weaknesses/challenges

Outdoor units must be located close to the apartments they serve. If condensers (outdoor units) cannot be installed on the roof due to building height they often must be mounted on an outdoor balcony or hung on an exterior wall. Installation costs must therefore account for scaffolding and potential work such as insulation, air-sealing, and cosmetic work if visual impact is a concern (Urban Green Council 2020). For this and other reasons, mini-splits are more suitable for low-to-mid-rise buildings, which is the dominant large multiunit apartment building type in the United States. They can be more challenging to install in high-rise buildings without outdoor spaces connected to the apartments. However, the Ephoca and other similar units discussed above can avoid this problem, though installation still requires drilling two holes per unit or new windows to permit below-the-window venting.

Despite technical improvements for cold climates, performance decreases at colder conditions; in many cold climate applications, backup heat is needed for peak winter temperatures.

Mini-splits require refrigerant lines to be installed on site and thus are more prone to refrigerant leaks than systems that come pre-charged.

Given the fact that mini-split and VRF systems are probably the most common types of multifamily heat pump retrofit to date, table 3 summarizes mini-split strengths and weaknesses relative to VRF systems.

Table 3. Comparison of mini-splits and central VRF systems

Mini-split strengths	Mini-split weaknesses relative to VRF
Lower upfront costs	Higher visual impact
Higher measured performance	More challenging to install in high-rise buildings
Easier to install and repair	Require more envelope penetrations
Lower refrigerant charge than VRF	

Window heat pumps

Key takeaways

- Window heat pumps are lower cost than the other heat pump options examined in this report; while they are just reaching the market, they have performed well in initial applications.
- Present systems are only designed for single- or double-hung windows and the aesthetics of these units will not appeal to all building owners.
- Operating costs are generally on tenant meters, adding a significant tenant cost unless rents are reduced proportionately.[11]

Introduction

Window heat pumps are a variation on window-mounted air conditioners, but in recent years new models have entered the market with improved performance and minimized window blockage. In 2021 the New York City Housing Authority (NYCHA) held a competition to choose suppliers for 30,000 window heat pumps that they would install in public housing they owned. The competition included a variety of criteria including good performance in cold weather. Ultimately, two manufacturers were selected: Gradient (a San Francisco-based startup) and Midea (a large Chinese manufacturer) (Housing Finance 2022).

In addition to these two new products, a variety of manufacturers produce heat pumps that fit in a window, just like window air conditioners (Takemura 2024). These generally have lower heat output and efficiency than the new products. Some through-the-wall room air conditioners can be replaced with through-the-wall heat pumps, although the size of the openings can severely restrict what heat pumps could be used. We did not include these more traditional products in our analysis.

Availability

Gradient and Midea are both now selling a cold climate window heat pump to building owners and energy efficiency programs directly. These saddle-shaped products fit in a window but mostly hang below the window, leaving most of the window unobstructed (see figure 5). Both units use 120-volt power and plug into a normal home electrical outlet.

[11] This same issue sometimes applies to mini-split units: Sometimes these are placed on tenant meters, sometimes on landlord meters.

Figure 5. The Midea unit (top) and Gradient unit (bottom). Source: Midea and Gradient.

The Gradient unit is manufactured in India, the Midea in China.

Both the Gradient and Midea units are roughly 25 inches wide and designed for single- or double-hung windows, such as the window shown above in figure 5. A 2013 survey estimated that 61% of residential windows in the United States are single-hung (particularly common in the South) or double-hung (particularly common in the north) (Bickel, Phan-Gruber, and Christie 2013). In multifamily buildings in California and elsewhere in the West, slider windows are common and an alternative window heat pump form factor will be needed. The California Market Transformation Administrator (Cal MTA) is now developing an initiative to spur availability and use of these narrower units (Cal MTA 2025). [12]

System costs

Midea reports that their units will cost $3,000 apiece while Gradient has a manufacturer suggested list price of $3,800 (Takemura 2024). These prices are for small quantities and bulk purchases are likely to be priced lower. The price NYCHA is paying is not public. Some energy efficiency program implementers report that current prices with installation are as much as $1,500–2,000 higher than those quoted by Takemura. For our main analysis, we assume an average future price of $3,000 per unit (in 2024$). These prices are for the units only. Both the Gradient and Midea units need a dedicated 15-amp circuit; a new circuit, if required, will add an additional cost. Also, as with any electric heat pump option, an electrical load assessment has to be done for the building. Based on the NYCHA experience, we assume one window heat pump per bedroom plus one for the living room. In addition, for apartments of 1,500 sq. ft. of floor area or more, we include a second unit in a common space, in addition to the bedroom and living room units. A presentation by NYSERDA (2024a) estimates one hour for maintenance staff to install mounting brackets and then each unit (two staff, half an hour each) and an additional hour to remove each radiator. In the NYCHA project this work was done by their maintenance staff. If we value this time at $50 per hour, this is an additional $100 per heat pump. But if contractors need to be hired, costs are likely to be substantially higher.

Performance

Heat output varies with unit size and outdoor temperature. According to Gradient, heat output ranges from 7,026 Btu/hour at –13°F to 9,000 Btu/hour at 17°F and higher temperatures. The Midea unit has a claimed heat output of 9,008 Btu/hour at 47°F and 8,864 at 17°F.

Data on the performance of the two units are summarized in table 4. The two units are very similar in heating capacity, dimensions, and efficiency. As a measure of seasonal efficiency, the Midea unit has an HSPF2 rating of 10.1 while the Gradient is 9.3 (Midea 2024; Gradient 2024b). These are approximately a seasonal COP of 2.96 and 2.73, respectively. For our analysis we take the average of these two values, but then reduce this 2.84 average COP by 10% to account for the difference between lab and field performance, resulting in an assumed COP of 2.56.[13]

Table 4. Technical specifications of the Midea and Gradient units

Midea heat pump specifications	Gradient heat pump specifications
120 VAC / 12 A / 60 Hz	120 VAC/ 12 A / 60 Hz
Btu/Efficiency	Btu/Efficiency

[12] One reviewer noted that technically you could replace these windows with single- or double-hung windows, but this would be expensive.

[13] An evaluation of the field performance of the NYCHA window heat pump demonstration project is underway but not available in time for us to use in our analysis. In the absence of field data, we assume a 10% field degradation factor; this is half what NYSERDA (2022) found for mini-splits. We cut the degradation in half because with window HPs the refrigerant is pre-charged, and there will not be efficiency losses due to refrigerant lines or improper charge.

Midea heat pump specifications	Gradient heat pump specifications
9,100 at 95°F / 11.81 EER	9,000 at 95°F / 13.6EER
9,000 at 47°F / 4.00 COP	9,000 at 47°F / 4.04 COP
9,000 at 17°F / 2.42 COP	9,000 at 17°F / 2.37 COP
9,000 at 5°F / 2.00 COP	7,200 at 5°F / 2.06 COP
10.1 HSPF2	9.3 HSPF2
Operation down to –13°F	Operation down to –7°F
Variable speed compressor	Variable speed compressor
R-32 refrigerant	R-32 refrigerant
51 Max dB(A)	47 Max dB(A)
Weight: 130 lb.	Weight: 140 lb.
Dimensions: 25.5” W × 35”–41” D × 20.5” H	Dimensions: 25.5” W × 37”–47.4” D × 24” H

Data include several more recent changes to the Gradient specification provided by Gradient. HSPF2 comes from manufacturer literature. Seasonal COP is estimated by taking HSPF2 and dividing by 3.412 Btu per watt-hour. Source: Building Energy Exchange 2025.

Experience to date

Both units are now being used in a NYCHA demonstration project (a total of 74 units in 24 apartments) (Takemura 2024). Preliminary results over the first winter are about an 87% reduction in Btu per sq. ft. for heating relative to steam heating in matching apartments and a 50% decrease in energy costs per apartment per heating degree day (Building Energy Exchange 2025).

Surveys of residents indicate general satisfaction with the new units, as summarized in figure 6.

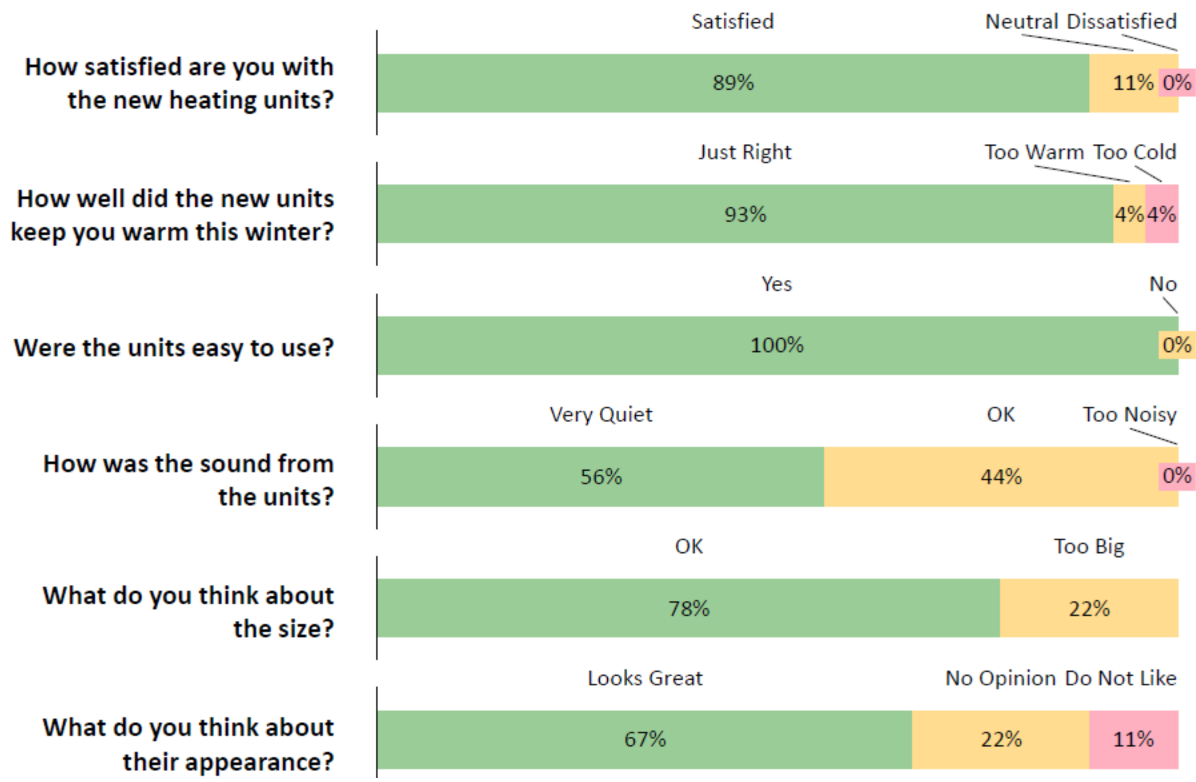

Figure 6. Survey results for residents using the new heat pumps in the NYCHA demonstration project. Sample size is 72 responses. Source: Building Energy Exchange 2025.

As a result of the pilot, both manufacturers have made some modifications to their units to improve performance, addressing such issues as installation brackets, condensate disposal, and the user interface.

Midea is field testing several units with their employees in the Louisville, Kentucky, area, including at temperatures below 0°F during a recent cold spell. Gradient has done initial customer deployments in the Northeast, the Northwest, and California. NYCHA is planning a larger demonstration project in 2025 in which they will convert two entire buildings, one each for the two products. The Northwest Energy Efficiency Alliance, Electric Power Research Institute, Vermont Energy Investment Corp., Eversource, and National Grid are all purchasing units for pilot programs. Several other pilot projects are in discussion but are not yet public.[14]

Strengths and weaknesses

These new window heat pumps do not block windows, provide substantial heat, and have a good COP. They also provide cooling, something many units in large, older apartment buildings in the northern United States now lack.

Several units will be needed to heat and cool an apartment: The NYCHA demonstration project is generally using three units per apartment, in the living room and each bedroom. At a long-term cost of $3,000 per unit, plus $100 per unit per installation (as discussed above), this means a $9,300 cost

[14] Information in this paragraph comes from personal communications with Brian Langness at Midea and Jason Wexler at Gradient, January 2025, and also with some of the companies mentioned.

(2024$) for a typical two-bedroom apartment, but less for small apartments with fewer bedrooms and more for large apartments. These costs will most likely be the responsibility of landlords.

The units weigh about 130–140 lb. each, so installing them will generally require two people. These heat pumps (as well as the other in-unit systems) introduce a maintenance need that is within the apartment, mainly the need to clean fan filters. Buildings will either need to rely on residents to periodically clean their filters, or have that done by management or a contractor.

Some people may not like the aesthetics of these units on the outside of buildings (see figure 7). Due to their width, current products will generally only work in single- and double-hung windows, although development work is underway on narrower but deeper products.

Figure 7. Outside view of the Gradient unit. Source: Gradient 2024a.

Window heat pumps will commonly be used in older buildings with central heating systems. The new heating units are plugged into a regular outlet in the apartment; 15 amps of capacity is needed. Usually the landlord pays for central heat and the tenant pays for in-apartment electricity use, so installing window heat pumps will often switch heating costs from the landlord to the tenant unless special arrangements are made (we elaborate further on this issue in the discussion section).

Packaged terminal heat pumps

Key takeaways

- These units can be a good, moderate cost option for apartments that now use PTACs for cooling but will generally not be appropriate for other apartments.
- New products designed for cold climates will likely be available in the next few years.

Introduction

Packaged terminal air conditioners and heat pumps (PTACs and PTHPs) are used to cool and heat many hotel rooms and some multifamily apartments. PTACs provide cooling and often include electric resistance heating coils. Some customized PTACs include heating coils that are served with hot water generated in a central boiler system. PTHPs include a reversing valve and additional controls so they can use the refrigeration system to provide heat. These units often have electric resistance backup. A sample unit and an exterior view are illustrated in figure 8.

Figure 8. Packaged terminal heat pump, interior and exterior views. Sources: Home Depot and Gothamist.

If an apartment already has a PTAC, installing a PTHP is often a viable option. Installing a PTHP in an exterior wall that was not designed to incorporate a PTAC is usually expensive and thus likely not a viable option.

PTACs and PTHPs in existing buildings must fit in the existing opening in order to avoid high retrofit costs if the opening size needs to be changed. Most current PTHPs are not very efficient and are designed to provide heat only down to outdoor temperatures in the 30s Fahrenheit. The opening size limits the potential to increase PTHP efficiency substantially, although making the units deeper is sometimes possible (Taitem Engineering 2018).

As noted in the mini-split section, Fujitsu now offers a split terminal heat pump (STHP) as an alternative to packaged terminal air conditioners (PTACs), in which the compressor is mounted within a sleeve in the exterior wall, meaning the system can be installed from the inside. This flexibility can lower installation costs and disruption to building occupants. This unit is illustrated in figure 9. As a mini-split, this unit has a higher efficiency than most PTHPs. Preliminary data from a demonstration project in a multifamily building in Brooklyn show an average decrease in energy costs, but details were not available (Dentz 2025).

Figure 9. Fujitsu split termal heat pump with the front cover off showing how the unit can fit into a PTAC cabinet

EIA's Residential Energy Consumption Survey (RECS) does not identify buildings with PTACs separate from other room ACs (i.e., window and through-the-wall air-conditioning units), making it difficult to identify how many apartments use these systems nationally and precluding the use of RECS data to analyze apartments that may be suitable for PTHP.

A study for NYSERDA estimates there might be around 250,000 PTACs in New York City, including many hotels as well as apartments. Quite a few of these units are customized units, built locally, that include heating coils linked to centralized boilers (Taitem Engineering 2018). Thus, it appears that NYC has a much higher proportion of multifamily buildings using PTACs than many other locations.

An example of a PTHP retrofit is the Gateway Plaza project in New York City. This 1,700-unit project built in 1983 needed updating. The original HVAC system used PTACs and electric resistance heat. The retrofit project installed new, more efficient windows, undertook other energy-saving improvements, and switched the HVAC to PTHPs. Upgrading the windows and PTACs required coordination with tenants. The completed project reduced building energy use (site energy use intensity) by 20% with most of the energy bill savings flowing through to tenants. Tenants also saw improved comfort as the old windows were leaky (Building Energy Exchange 2024).

To address the need for improved PTHPs, in late 2024 NYSERDA launched a program to encourage and assist manufacturers to develop improved PTHPs to replace PTACs for three applications: (1) standard-size PTACs, (2) PTAC in hydronic cabinets (i.e., customized units), and (3) through-the-wall air-conditioning. Applications were accepted through late February 2025 to qualify for Product Development Grants of up to $250,000 per product, per manufacturer to support new product development or modification of existing packaged terminal heat pump equipment as well as for Demonstration Project Funding of up to $1,000,000 per product, per manufacturer to fund the demonstration of the new PTHP product, including NYSERDA purchase of PTHP prototypes, product installation, and project management costs. NYSERDA is assembling a list of multifamily building owners who might be interested in working with manufacturers on demonstration projects. A total of $10 million has been budgeted for the program (NYSERDA 2024b). As of June 2025, grant recipients were not yet announced.

In addition, the Consortium for Energy Efficiency formed a PTAC committee in March 2025 to help coordinate utility and related programs on PTHPs; at the time of this writing there was no public information available on this initiative.

Variable refrigerant flow systems

Key takeaways

- VRF systems are complex, expensive, and have generally not had good performance in multifamily retrofit applications.
- Given their limitations, many industry professionals agree that VRF heat pumps are not a good choice for retrofitting most multifamily buildings.
- Other options, such as mini-splits and newer heat pump options like window heat pumps or single-package system (e.g., Ephoca) should be considered first.

Introduction

Variable refrigerant flow (VRF) systems are a type of electric air-source heat pump (ASHP) technology that uses a variable speed drive to modulate refrigerant flow to apartments based on heating and cooling demand, optimizing efficiency and temperature when designed and installed correctly. They are most effectively used in buildings that may be heating in some zones and cooling in others at the same time (e.g., mixed-use, hospitality, and large office buildings). While VRF is an emerging option for electrification in multifamily buildings (Building Energy Exchange 2021), its advantages in this application are uncertain. The need for simultaneous heating and cooling is rare in multifamily buildings, except for those that also contain other uses such as office or retail. Even then the economics may not work out, because VRF systems can be expensive and installation problems often reduce efficiency.

Centralized VRF systems are modular, with one outdoor unit serving multiple indoor units (see figure 10). Compared to mini-split systems, which commonly require one outdoor unit for one to three indoor units, centralized VRF reduces the amount of equipment to locate and maintain. However, installation can be complicated by the need for longer and more complex electrical and refrigerant lines. In retrofit applications, additional upgrades to ancillary systems such as electrical and envelope can further increase installation costs (NYC Accelerator 2019).

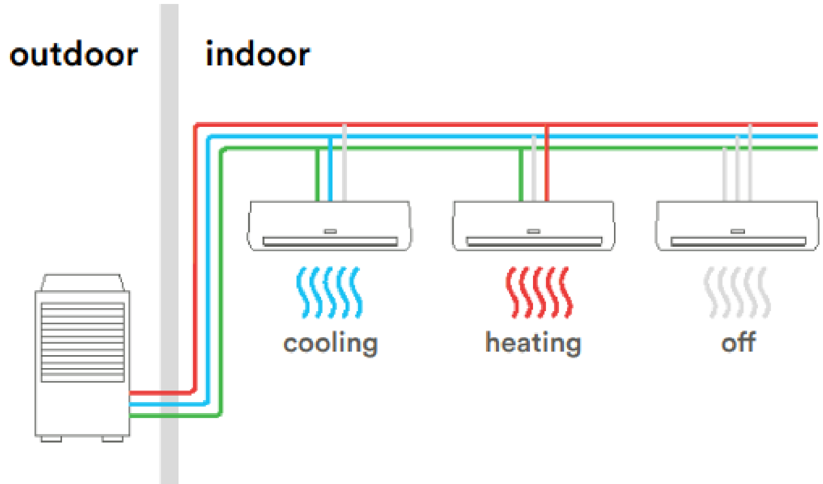

Figure 10. Central VRF system with heat recovery and simultaneous heating and cooling. Image source: Building Energy Resource Hub.

All VRF manufacturers in the United States offer a heat recovery package, which enables simultaneous heating and cooling within the same zone. While this feature can improve efficiency, it increases capital costs due to additional controls and a third refrigerant line. Heat recovery is only cost effective for buildings with diverse heating and cooling loads, where excess heat from one zone can be reused in another.

Multifamily buildings are less suited for heat recovery for the majority of their heating compared to other commercial buildings because their heating and cooling loads are more directly influenced by outdoor temperature rather than internal zones. Because of this, they are less likely to benefit from the heat recovery capabilities that are one of the key selling points of VRF systems. That said, multifamily buildings do have year-round domestic hot-water loads, providing more limited opportunities for heat recovery; we profile one such project later in this section.

Availability

Market

The market for VRF systems in the United States has been growing over the last 20 years (VEIC 2023). It is among the fastest-growing segments of the split-system HVAC market with a projected compound annual growth rate (CAGR) of 6.34% from 2025 to 2032, driven in large part by the demand for more energy efficient HVAC systems (Data Bridge Market Research 2025). Manufacturers continue to release products with higher efficiency, particularly focusing on cold climate applications.

VRF technology is widely available nationally and is being used increasingly in multifamily new construction applications (NEEP 2019).

Manufacturers

Top manufacturers and the names of their VRF product lines include

- Daikin (VRV)

- Mitsubishi (CITY MULTI)
- Fujitsu (Airstage)
- LG (MULTI V)
- Panasonic (ECOi)

Currently, all equipment components (indoor and outdoor units, distribution systems, and controls) are manufacturer specific, so a single manufacturer would be required to supply the entire system. A third-party control system may be required to collect data required for billing/submetering (SWA 2019).

System costs

An ACEEE report from 2022 estimated the retrofit installation cost of central VRF systems in multifamily buildings at $18,200–27,300 per apartment. These costs were based on a study from Urban Green Council (2020) that analyzed VRF retrofit costs for eight buildings in NYC. ACEEE increased the cost by 25% at the low end and 50% at the high end based on evidence that actual retrofit installation costs in NYC apartments are higher than estimated by Urban Green (Nadel and Fadali 2022).

An average installation cost estimate from a NYC contractor is $15,000/ton of capacity. Assuming a typical apartment has a heat load of one ton (SWA 2019) and adding 10% for incidental painting and carpentry, 25% to upsize the unit to account for distribution losses, and 15% for electrical upgrades for buildings built before 1946, this comes to $23,719 per apartment (M. Zuluaga, cofounder and chief revenue officer, Cadence OneFive, pers. comm., January 2025).

According to an unpublished presentation from a Climate Week Convening on Commercial VRF for Multifamily Buildings, construction costs for central VRFs ranged from $23–76/sq. ft. (average $39/sq. ft.) with a sample size of seven projects in New York City. If the average apartment is 1,000 sq. ft. (SWA 2019), this means $39,000 per apartment. Cadmus estimates $38,000 including $5,000 for additional electrical work based on an analysis of 15 multifamily heat pump retrofits in NYC (Building Energy Exchange 2025).

According to another unpublished presentation at the Climate Week Convening on Commercial VRF for Multifamily Buildings, central VRF systems cost 24% or more than small mini/multi-split heat pumps, while other sources report the difference can be as much as 50%. The higher costs may be due to their complexity, which increases installation costs, and the fact that there are fewer manufacturers of VRF systems than mini/multi-split systems, resulting in less competition.

As presented, cost estimates range widely, with nearly all of these from New York City, which is known for high costs. The range of costs is illustrated in table 5. Given this range, we use $20,379 for our primary analysis, which is 24% more than our midpoint national estimate for mini-splits, as discussed in an earlier section of this report. This is lower than some of the recent New York City estimates and may be generous to VRF systems.

Table 5. Examples of installed costs for VRF in multifamily buildings

Source/Case study	Installed cost (2024$)
Steven Winter Assoc. 2019	$21,416

Urban Green 2020	$21,928
Zuluaga, M. 2024	$23,719
ACEEE (Nadel and Fadali 2022)	$25,753
Cadmus, as cited in Building Energy Exchange 2025	$38,000
24% more than national price of mini-split	$21,472

Note: Pre-2024 costs were adjusted to 2024$ using the Federal Reserve Implicit GDP Deflator.

Performance

Several recent studies of installed central VRF systems show low energy performance compared to rated efficiencies, with one study reporting 77% higher heating energy consumption than mini-splits (NYSERDA 2021). The same study cites two other studies of large VRF systems that report low COPs: 1.2–2.0 in the first (Lee et al. 2018) and 1.4–1.75 in the second (Southard 2014). Consistent with the above, an unpublished presentation at the Climate Week Convening on Commercial VRF for Multifamily Buildings reported a measured VRF COP for large VRF in multifamily buildings ranging from 1.0–1.8, with an average of 1.6.

Reasons cited for low energy performance in these studies include (1) losses due to long refrigerant runs, (2) low equipment efficiency ratings at low temperatures and part load conditions, (3) pressure drop at fittings, and (4) continuous refrigerant flow, even when there is no call for heating or cooling (Taitem Engineering 2020).

Experience to date

New York's HCR's Sustainability Guidelines for existing buildings now include specifications for VRF in adaptive reuse projects. Despite growing support for the technology, however, few multifamily buildings in the United States have completed the installation of a central VRF system in a retrofit application.

As noted previously, multiple studies have cast doubt on the appropriateness of VRF for multifamily applications due to high installation costs and often lower-than-expected system efficiency once installed. Despite their potential benefits, such as improved comfort, tenant control, and potential for energy savings, these challenges have led to skepticism about their effectiveness in this context (Shapiro 2024b).

One multifamily project where a VRF system has worked well is the Ken Soble Tower in Hamilton, Ontario (near Toronto). Built in 1967, the building needed a complete renovation. A new envelope was installed (windows and exterior insulated cladding), which dramatically reduced heating loads and brought the building up to Passive House standards. Heat needs were low enough that heat could be provided via VRF systems that temper ventilation air provided to each apartment. Heat recovery from exhaust air preheats the ventilation air, and further heat is provided when needed via supplementary coils in each apartment that receive warm refrigerant from the VRF system. The retrofit reduced energy use per sq. ft. of floor area by 65%. The design team estimates that the Passive House features added 5–10% to the cost of the renovation (Nagy 2020; Building Energy Exchange 2025).

When installed correctly, central VRF systems can potentially reduce maintenance costs compared to separate heating and cooling systems. One outdoor unit can supply multiple indoor units, meaning fewer pieces of equipment to purchase and maintain, and fewer envelope penetrations. As with the system types discussed in earlier sections, distribution is ductless, making them appealing for retrofit applications with space constraints where installing ductwork may be cost prohibitive.

Central VRF is most cost effective in buildings with diverse space conditioning zones (e.g., buildings with multiple exposures or, for example, buildings with substantial data centers), especially where heat recovery can be used. Note that heat recovery is not cost effective if the building does not have sufficiently diverse heating/cooling loads, as is the case in most multifamily buildings (NEEP 2019).

Central VRF systems have higher upfront equipment and installation costs; costs can be significantly inflated due to upgrades required for proper installation and operation (i.e., electrical upgrades, structural upgrades for heavy outdoor equipment, and costs of complex refrigerant runs). Space and time are also considerations for locating equipment and new electrical and refrigerant lines. As with mini-split systems, coordinating in-unit work is often time consuming, too (NYSDPS 2024).

System performance is highly dependent on correct installation and operation. To optimize efficiency, the VRF system must be appropriately sized according to the load requirements of each space. An oversized system will increase capital costs and operating costs. Refrigerant runs must also be designed to minimize length for optimal refrigerant distribution. These steps can reduce costs and improve performance, yet the economics of VRF systems are likely to remain challenging.

Maintenance costs may be higher and more complicated because some repairs require a qualified third-party technician. Currently, fewer contractors are qualified to install and/or service central VRF than mini-split heat pumps (NYSERDA 2021). Furthermore, equipment failure, especially at the outdoor unit, puts more apartments at risk while equipment is repaired. A higher risk for refrigerant leakage results from long refrigerant runs.

Metering needs vary by application and may require additional installation and operating costs to enable submetering. A discussion of metering options is included in the section “Who Pays for Heat?”

Condensing boilers using alternative fuels

Key takeaways

- Life-cycle analysis reveals that alternative fuels have substantial carbon emissions (Traynor and Waite 2025), and are therefore not a full decarbonization solution for multifamily retrofits.
- Condensing boilers using alternative fuels can be an option when optimizing for capital cost but an all-electric heat pump system is preferable when optimizing for decarbonization (Zhou and Wang 2021). Condensing boilers are less efficient than heat pumps.
- Low return water temperature, the most important factor in condensing boiler efficiency, is significantly affected by equipment sizing, outdoor reset controls, and burner modulation; training for boiler operators and contractors in design and operation is critical.
- To date, some boilers operate on a mix of fossil and reduced carbon alternative fuels (e.g., methane made from biomass), but very few boilers now operate on just alternative fuels. Thus, a boiler operating on just alternative fuels is a potential option for the future but not a viable option for today.

Introduction

While we found no examples of condensing boilers fully fired with alternative fuels, condensing boilers burning natural gas or propane are an established technology for both residential and commercial applications, offering a high-efficiency alternative to conventional hot-water boilers. Condensing boilers can achieve an efficiency of 90–96% compared to efficiencies in the 1980s for noncondensing technologies.

This higher efficiency is achieved by capturing latent energy in flue gases and transferring that heat into return water. To achieve condensation, the system must be designed and operated such that the return water temperature is below 130° F (Cutler et al. 2014).

Commercially available oil boilers cannot achieve condensing operation. In regions without access to natural gas or where switching to natural gas or propane is not feasible, many high-efficiency oil boilers compatible with alternative fuels are available with efficiencies of 87–91% Annual Fuel Utilization Efficiency (AFUE) (Langer 2022). Though less efficient than condensing boilers, they perform significantly better than older oil boilers, which typically operate at around 58–75% AFUE (U.S. Department of Energy 2025).

In 2022, ACEEE presented preliminary findings that in multifamily buildings where the energy use per apartment is low and the cost of electrification is high, installing a condensing boiler using natural gas could minimize life-cycle costs (Nadel and Fadali 2022). This previous analysis looked at fossil gas and did not consider the impact on decarbonization. However, much additional technology development and demonstration projects with low-carbon alternative fuels will be needed to establish this approach as a viable carbon reduction option.

Alternative fuels

Some alternative fuels that are chemically similar to fossil fuels, such as some biofuels and synthetic fuels, can be used in condensing boilers with no change in performance. Replacing traditional fossil fuels with alternative fuels can reduce net greenhouse gas emissions, as the CO_2 absorbed by feedstock growth offsets some of the combustion emissions. However, the fuels are not net zero, as significant emissions are associated with their production, maintenance of their distribution system, and land-use changes for feedstock—issues that would be exacerbated if production were to scale significantly. For this reason, condensing boilers using alternative fuels are not considered a full decarbonization option for retrofits. Furthermore, these fuels do not mitigate the air quality issues associated with burning fossil fuels (e.g., NOx emissions) and can sometimes worsen air quality vis-à-vis fossil fuels (Traynor and Waite 2025).

For this study, we consider three alternative fuels: biomethane (sometimes referred to as "renewable natural gas"), renewable diesel, and renewable propane.[15] All of these have been engineered to be

[15] Renewable diesel is now sold for use in vehicles but could be burned in space heating equipment. Currently, biodiesel is sometimes used for space heating, but a mix of 20% biodiesel and 80% conventional diesel is more typical. Burner modifications are required to burn biodiesel in higher concentrations. Biodiesel can be chemically altered to be nearly identical to conventional diesel and burned in existing burners. The conversion process has some costs; hence, renewable diesel will be more expensive than 100% biodiesel. Renewable propane is not being produced in large quantities, but several production paths are in development (Nadel and Fadali 2024).

chemically similar to the fossil fuels they replace and therefore can be burned in existing equipment without modification (Traynor and Waite 2025). A significant benefit of using a drop-in fuel like biomethane or renewable diesel is consistency in performance, as essentially the same fuel is being used.

Availability

The market for condensing boilers is on the rise in the United States due to their high efficiency and potential to reduce operating costs and carbon emissions (Gupta and Chaudhary 2024). In 2023 condensing boilers held more than a 67% share of the commercial boiler market (Market.us 2024). Manufacturers continue to push to improve designs and develop more efficient products that are compact and easier to install and maintain. Boiler efficiency is regulated by federal efficiency standards, but the existing standard is many years old and permits noncondensing products to be sold.[16]

Availability of alternative fuels depends on supply, demand, and distribution. Currently, the market for alternative fuels is limited, and the future market is uncertain (Traynor and Waite 2025). A few utilities blend biogas with fossil gas, such as PG&E, which aims to supply 15% biomethane by 2030 (PG&E 2024). However, no utility in the United States presently supplies anywhere near 100% biogas. Renewable diesel, a biofuel that can be burned in oil boilers, is available for purchase in a few locations but most oil dealers do not presently provide this product.

Some manufacturers are developing units designed specifically for use with additional alternative fuels such as hydrogen. For example, Viessmann has introduced the Future Fuels Ready Vitoladens 300-C condensing boiler for one- to two-family homes, which includes a retrofit kit for conversion from natural gas to hydrogen (Viessmann 2021). Other top manufacturers of condensing boilers for multifamily housing include AERCO, Weil-Mclain, and Cleaver Brooks.

While not examined in detail in this report, we note that several manufacturers offer biomass boilers suitable for multifamily retrofits, including Fröling, ANDRITZ, and Thermax. Wood pellet boilers make up 41% of the global market for biomass boilers, accounting for the largest market share (Grand View Research 2024). These units have automated equipment to feed pellets into the boiler.

System costs

The National Renewable Energy Laboratory (NREL) reports an average total installed cost of $48.17 per kBtu of hourly heating capacity for condensing boilers in multifamily retrofits (Cutler et al. 2014). If we assume the typical apartment has a heating demand of 12,000 Btu per hour (SWA 2019), and adding 25% to account for distribution losses (Rose and Kragh 2017), this is a cost of about $723 per apartment in 2012$. Adjusting for inflation, this is a cost of $972 per apartment in 2024$.

[16] In 2023, DOE announced new appliance standards, including an efficiency standard requiring condensing technology for new commercial water heaters beginning in 2026, and proposing condensing technology for residential gas-fired hot-water boilers by 2029 (U.S. Department of Energy 2023a). This standard was remanded by the courts back to DOE for further analysis and the court found DOE’s subsequent analysis inadequate and vacated the standard set in 2023. A new rulemaking will now be needed, but based on experience in the first Trump administration, DOE is unlikely to set a new standard for these boilers in the second Trump administration.

EIA (2023b) reports a total installed cost in 2022 of $69/kBtu/hr. Using the same assumptions above and adjusting for inflation, this is a cost of $1,099 per apartment in 2024$. This is a national average and does not reflect the approximately 10% higher cost in urban areas where multifamily buildings predominate.[17] Adding this 10%, the cost is $1,209 per apartment.

For our analysis we use the EIA estimate for condensing boilers as that is a newer analysis, but note that this is close to the NREL estimate. We assume the same cost for propane boilers. For high-efficiency, noncondensing oil boilers we use a price from the same EIA (2023) report used for gas boilers. This price works out to $1,377 per apartment (2024$) including the 10% adder for urban areas.

We do not know of any public data on potential cost impacts of boilers that burn only alternative fuels. Absent any data, we assume the same capital costs as for high-efficiency natural gas, propane, and oil boilers.

Performance

As noted earlier, condensing boilers are the most efficient type of hot-water boiler on the market, with AFUEs ranging from 90–96% when installed and operated correctly (PNNL 2021). In theory, energy savings from replacing old, inefficient conventional boilers with condensing boilers can result in as much as 30% energy savings (Arena 2012).

Installed efficiency in retrofit applications has been found to be lower than rated efficiency (Landry et al. 2016). This is due to the systems' high sensitivity to operating conditions: Steady-state efficiency is highly impacted by return water temperature, which is influenced by supply temperature, flow rate, and heat loss across the distribution system.

A 2016 analysis of 12 buildings (eight commercial, four multifamily) in the upper Midwest evaluated the installed efficiency of condensing boilers under real operating conditions to identify opportunities to improve performance. On average, the study reported that installed efficiency was found to be about five percentage points lower than the average rated efficiency. Measures identified as improving performance were shown to increase savings by 3–5%. These included low-cost measures such as tuning and controls, as well as higher-cost improvements such as repiping (Landry et al. 2016).

Based on this analysis, we assume an average efficiency of 90% in the field for a gas or propane boiler, less an adjustment for distribution losses as discussed in the methodology section later in this report. For oil we assume an average efficiency of 87% (from EIA 2023b).

Experience to date

Since 2001, the market for condensing boilers has expanded, with more manufacturers offering a wider range of products, most now equipped with advanced on-board controls. Previously only a small portion of the market, condensing boilers now dominate the commercial boiler market (Landry et al. 2016).

In 2010, the General Services Administration's (GSA) Green Proving Ground (GPG) program replaced conventional boilers with condensing boilers at six federal facilities. At one facility, the condensing boiler plant operated at 94%, reducing natural gas consumption by 14%. This was attributed to consistent operation in condensing mode. At the other five facilities, post-retrofit energy savings ranged from 16–41%, though variation in performance reflected differences in site conditions and system design rather

[17] This issue is discussed in the section on mini-split costs.

than time spent in condensing mode (Cutler et al. 2014). Based on these findings, GSA recommended deploying condensing boilers in retrofits only when (1) the boiler has reached its end-of-life and (2) system upgrades can ensure a low return water temperature (Cutler et al. 2014).

A 2016 Minnesota Center for Energy and Environment (MN CEE) study of 12 commercial properties, including four multifamily buildings, found that the condensing boilers at the multifamily properties achieved higher efficiency than at the other sites. This was largely because multifamily buildings were occupied more consistently, giving the boilers more opportunity to operate under part-load conditions with lower return water temperatures, improving efficiency (Landry et al. 2016). These findings highlight why condensing boilers are well suited for multifamily.

Strengths and weaknesses

High-efficiency condensing boilers can lower energy consumption and onsite carbon footprint relative to noncondensing boilers. The combustion equipment tends to be more compact than conventional boilers, offering space savings and flexible installation in tight spaces.

Using an alternative fuel such as biomethane in a condensing boiler plant can reduce onsite greenhouse gas emissions. Price and availability of alternative fuels, as well as emissions impact, vary widely, and their use as a decarbonization measure in multifamily retrofits requires additional analysis (Traynor and Waite 2025).

Traditional condensing boilers designed to run on fossil gas may not operate optimally with alternative fuels with different combustion characteristics, leading to reduced efficiency and maintenance issues (Boiler World Update 2025). Manufacturers are increasingly developing technologies to improve boiler compatibility with mixed and alternative fuels (Bosch Industrial 2025).

The efficiency of a condensing boiler is highly dependent on design and operation. Insufficient guidelines for design and control of condensing boilers result in many systems underperforming, with owners not realizing efficiency gains from their investment in higher cost equipment (Arena 2012).

Replacing a conventional boiler with a condensing boiler will likely require a new flue and venting strategy to handle corrosive flue gases and condensate. The new flue will require a corrosion resistant lining, which adds cost. Proper venting may further increase costs and complicate installation, as the corrosivity limits where the flue can exhaust (Parker and Blanchard 2012).

Central air-to-water heat pumps

Key takeaways

- Central air-to-water heat pumps are centralized systems that can use existing building distribution systems. Backup heat will generally be needed on cold days to raise water temperatures in the distribution system.
- Only a few multifamily projects have been completed but initial experience indicates medium costs and good performance.
- While this approach could be effective for buildings with existing central hot-water space heating systems, it is unlikely to be feasible for other buildings.

Introduction

Large commercial buildings are commonly cooled with a central chiller system. With the addition of a reversing valve, control changes, and various other tweaks, new chillers can be modified to produce heat in heat pump mode (this is for new equipment; modifying existing equipment is difficult if not impossible). In the commercial sector, some chillers pull heat from a water or ground source; others use ambient outside air as their heat source. Smaller systems, such as the size needed for many multifamily buildings, are primarily air-source. These systems can be used as a central heating system in multifamily buildings, producing hot water that can then be circulated to radiators or baseboard units. In this report we use the term *central air-to-water heat pump* to describe these systems, rather than other terms such as *heat pump chiller*.

While central air-to-water heat pumps can produce cold water for cooling, this requires a distribution system designed for cooling, such as fan-coil units in individual apartments. Because adding these cooling distribution systems to existing multifamily buildings is expensive, central air-to-water heat pumps should be considered a heating system that does not provide cooling for multifamily buildings that do not already have central cooling.

Presently, there are two main types of central air-to-water heat pumps: modular and built-up. Modular units are produced in standard sizes (e.g., 30 tons of cooling capacity[18]) and multiple units are installed in a building to match the load plus one extra in case a unit is offline. A typical apartment may need a ton or more of capacity plus an allowance for distribution system losses, but this will vary based on size, climate, and energy efficient features. Built-up units are almost always larger and are built on order from a variety of standard sizes to match the needed characteristics for a building, commonly with some type of backup. Pictures of typical modular and built-up units are shown in figure 11. We focus on air-source units as these are the primary type now being used in multifamily buildings, but if there is a source of warm water, water-source heat pumps are an option.

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[18] A ton of cooling capacity is 12,000 Btu/hour, about the amount of cooling provided by a ton of ice.[19] In addition, we obtained cost data on a fourth project in NYC, which in 2023 cost $12,800 per apartment for the heat pump and electrical work, but an additional $13,400 per apartment for a new boiler, a new dedicated outside air ventilation system, an adiabatic dry cooler, new pumps, a heat exchanger linking the building loop to the heat pump loop, and extensive piping modifications. We did not combine this with the other three projects as it was a much more extensive project (B. Milbank, senior project development engineer, Ecosystem Energy, pers. comm., May 21, 2025). If we subtract 15% for high costs in NYC and convert to 2024$, these additional costs for the distribution system total about $22,740 per apartment.

Figure 11. Modular unit on the left, built-up unit on the right. Sources: *York and Trane.*

A central air-to-water heat pump will typically produce 130–140°F hot water. Older multifamily building radiators and baseboard units are generally sized for 160–180°F hot water (some systems use steam; we discuss these below). Water at 140°F will provide adequate heat on days that are not cold, for example, outdoor temperatures above roughly 30°F, although this will vary by building. When outdoor temperatures dip below this balance point, supplemental heat will be needed to raise the temperature of the distribution water. This can be achieved with an electric boiler (electric resistance heat). Another option is a water-to-water heat pump operating as a second stage after the air-to-water heat pump: A few buildings use an air-to-water heat pump to produce water of approximately 130°F, and a second-stage water-to-water heat pump to raise the temperature to approximately 180°F. These two-stage systems are more complicated and expensive, and also less efficient. Alternatively, a smaller natural gas, propane, or oil boiler can provide this supplemental heat. When fuel boilers are used, they can potentially be fired with certain alternative, lower carbon fuels.

Some older multifamily buildings have steam distribution systems, where steam is produced in a boiler and the hot steam rises through the building to serve steam radiators in individual rooms. Steam distribution is particularly common in New York City. Steam distribution systems are very inefficient, wasting a lot of heat (e.g., seasonal efficiencies of old steam boilers are on the order of 56–70%; DOE undated). To date, decarbonization of steam-heated buildings has generally required installing a new distributed heating system using mini-splits, window heat pumps, or VRF systems. But some industrial heat pumps can produce steam, and perhaps in the future industrial heat pumps can be used to produce steam for large multifamily buildings, although the problem of high heat losses in steam distribution would remain. Industrial heat pumps generally use different refrigerants than commercial air-to-water heat pumps. More information on industrial heat pumps can be found in ACEEE 2025.

We also note that NYSERDA has initiated a competition for a $10 million prize for low-carbon heating solutions for tall commercial and multifamily buildings. Seven finalists were announced in July 2024, including several who are developing heat pumps to produce high temperature hot water and/or steam (NYSERDA 2024c).

Availability

Presently, central air-to-water heat pumps are produced in North America by two major manufacturers, with two other manufacturers planning to introduce products in 2025. These products were generally first developed and marketed in Europe and then the designs were Americanized for production in the United States. In addition, a variety of products produced in Europe and Asia can be imported after modification for U.S. voltages and certification for U.S. technical standards.

The two current manufacturers in North America are York (a division of Johnson Controls) and Trane. Information on these units as well as a couple of units produced in Italy that have recently been used in U.S. multifamily retrofits is provided in table 6.

Table 6. Summary information on central air-to-water heat pumps now produced or installed in North America

Manufac-turer	Model	Cooling capac.	Heating capac.	IPLV	COP 47F	Refrigerant
Trane	AXM	30 tons	390 kBtu			454B
Trane	ACX	140–230 tons	1500–2500 kBtu			454B
York	YMAE	35 tons	458 kBtu	20.01	3.45	454B
Aermec	NYG 0500	27–30 tons	329–379 kBtu	13.3	2.78–3.02	454B
Aermec	NYG 1000-1800 HP	83–137 tons	953–1560 kBtu	16.1-16.7	2.95–2.97	454B
Galetti	PLI	35–55 kW	35.7–53.9 kW		2.95–3.19	454B
Galetti	PLE	50–160 kW	59–172 kW		3.2–3.24	454B

Note: "k" under heating capacity means thousand. IPLV is a standardized estimate of average efficiency in Btu/watt-hour. Sources: Manufacturer product literature.

In addition, Carrier and Daikin-McQuay are planning to introduce models to the U.S. market in 2025. Carrier is developing two products, a 30-ton modular product and a 200–250-ton built-up product. In future years the latter line will expand to include a 400-ton built-up product (T. Cates, commercial sales general manager—Applied Distribution East, Carrier, pers. comm., October 2024). Daikin-McQuay now imports a 25-ton modular product from their European operations and is developing a 70–250-ton built-up product for the American market (B. Dietrich, director, Chiller Applications, Daikin Applied, pers. comm., October 2024).

System Costs

We obtained costs for three projects, all in the Northeast. The most expensive of the three is in New York City, with a cost per apartment of $14,853 in 2024$ (Asit Patel, ANP Energy Consulting Services Corp., pers. comm., February 2025). The other two projects are in Massachusetts, but the figures we were given are approximate. Two of these projects are completed while one has a contracted cost with installation scheduled for the summer of 2025. Two of the projects are heating only; the third project includes cooling because the existing building already has central cooling using fan coils in each apartment. All three of these projects retain a boiler as backup. If we discount the NYC cost by 15% (as discussed in the mini-split section of this report), across all three projects the average cost per apartment was $13,359 (2024$). We used this average for our analysis.[19] This cost does not include the boiler or a new distribution system.

[19] In addition, we obtained cost data on a fourth project in NYC, which in 2023 cost $12,800 per apartment for the heat pump and electrical work, but an additional $13,400 per apartment for a new boiler, a new dedicated outside air ventilation system, an adiabatic dry cooler, new pumps, a heat exchanger linking the building loop to the heat pump loop, and extensive piping modifications. We did not combine this with the other three projects as it was a much more extensive project (B. Milbank, senior project development engineer, Ecosystem Energy, pers. comm., May 21, 2025). If we subtract 15% for high costs in NYC and convert to 2024$, these additional costs for the distribution system total about $22,740 per apartment.

One option for maximizing heat provided by a central heat pump system is to install new radiators designed for hot water at temperatures heat pumps can produce. These radiators are common in Europe and have been installed in some U.S. projects. These radiators are now being installed in three NYC projects, with costs per apartment ranging from $6,700–10,100 per apartment (2025$) (Asit Patel, ANP Energy Consulting Services Corp., pers. comm., February 2025). Our analysis does not include new distribution systems; such new systems increase both costs and efficiency (the latter is discussed below).

Performance

An average seasonal COP of 2.52 is projected for the first project discussed in the next section. Actual field performance data are not available yet. This COP is for the heat pump and does not include distribution system inefficiencies (Dentz 2025).

Experience to date

The Association for Energy Affordability (AEA) has installed two central air-to-water heat pumps in multifamily buildings in New York City. The first project is a 38-unit building in the Bronx. Two-stage Aermec heat pumps were installed, with the first stage an air-to-water heat pump and the second stage a water-to-water heat pump that can raise the water temperature to 180°F. This was a complicated system for which the operator and service staff have needed training. The second AEA project is a 48-unit building. A single-stage Aermec air-source heat pump was installed. For the first winter the existing boiler was used to raise hot-water temperatures on cold days. A second stage of the project will install European-style radiators sized to fully heat the apartments on cold days with 140°F distribution water temperatures (Asit Patel, ANP Energy Consulting Services Corp., pers. comm., January 2025).

Eversource Massachusetts, which serves Boston and substantial other areas of the state, is helping to fund installation of these systems in two multifamily buildings in Eastern Massachusetts. The first system will be at a 100+ unit building in New Bedford, Massachusetts. The new air-to-water heat pump will replace an existing chiller and will provide cooling as well as the majority of heat for the building, with the existing boiler retained as a supplement when outdoor temperatures get low. This building has fan coils in each apartment that use the warm water provided by the boiler in winter and the cold water provided by the chiller in summer to heat and cool each apartment. The new heat pump system is being installed in the summer of 2025.

The second system is planned for a multifamily high rise in greater Boston, but they are encountering site barriers such as the need for noise abatement, proximity of the equipment to a subway and to play areas, and electric capacity barriers, which include older electrical infrastructure, lack of adequate electric capacity, and at one site, the need to trunk the electric supply to the roof. Eversource has almost finalized the site but is now investigating whether mitigating these barriers might be cost prohibitive.

Strengths and weaknesses

These centralized systems can generally use a building's existing distribution system. Because it is a centralized system, the landlord will generally continue to pay for heat. These systems often have higher energy efficiency than the other system types discussed earlier in this report, not counting the distribution losses. However, these systems would likely not be feasible in a building not currently distributing hot water for space heating.

These systems are generally larger than an existing boiler and thus space will often be needed beyond the boiler room, such as outside. Not all buildings have this space. Depending on the site and system, roof reinforcement, hot-water storage tanks, and electric distribution improvements may be needed. These are new systems and application experience to date is limited, with very little experience in multifamily buildings in particular.

While available data are limited, these heating-only systems appear to be lower cost per apartment on average than mini-split and VRF systems. Costs can be substantially higher if distribution systems need to be modified to add cooling capabilities or for a major rework of the distribution system as described in footnote 19.

Heat recovery chillers

Key takeaways

- Heat recovery chillers can be very high efficiency, but these complex systems require a heat source.
- For multifamily buildings, this limits their application to mixed-use buildings or large buildings that can incorporate thermal storage.
- While this approach could be effective for buildings with existing central chilled water and hot-water HVAC systems, it is likely unfeasible for other buildings.

Introduction

Heat recovery chiller heat pumps are more efficient than central air-to-water heat pumps because they produce both hot water and chilled water. As a result they can, for example, use heat ejected from a cooling system, for space heating. Thermal energy storage tanks allow load shifting when building space heating and cooling needs are not simultaneous.[20] The heat sources used by heat recovery chillers are warmer than outdoor air in winter, allowing the heat pump to operate more efficiently; however, to take advantage, a building must have sufficient simultaneous heating and cooling and/or thermal energy storage. Heat recovery chillers are complicated and thus they are primarily an option for very large multifamily buildings, particularly those that are part of a mixed-use building that combine apartments with commercial uses that need cooling even in the winter. These heat recovery systems often use water-source screw chillers, which are more efficient than air-source reciprocating chillers, even without counting the benefits of heat recovery. Combining the efficiency of heat recovery and large, more efficient chillers commonly results in a heating COP of 3–7 (Stein and Gill 2024), varying with the system and the amount of heat recovery available: for example, COP toward the lower end of this range in heating-only mode and toward the upper end with extensive heat recovery (ASHRAE 2022). Because of their cost and complexity, they are generally sized to the minimum simultaneous heating and cooling loads, with other chillers and boilers used to meet additional loads.

To address asynchronous demand, heat recovery chillers with storage tanks can hold warm or hot water generated when building heating needs are moderate and extra heat pump capacity can be used to heat water. This warm or hot water then becomes a heat sink to extract heat from during times of high

[20] A related, but different, approach is to use traditional chillers for cooling and to use the chiller's condenser water for space heating. Because the condenser water may not be warm enough for space heating at low outside air temperatures, an AWHP can be used to boost the hot-water supply temperature. All-electric hydronic system retrofits in colder climates are relatively new and engineers are pursuing several different design strategies appropriate for specific buildings and systems.

heating demand, as illustrated in figure 12. Furthermore, due to this storage capacity, less heat pump capacity is needed to fully heat a building, potentially saving space as illustrated in figure 13.

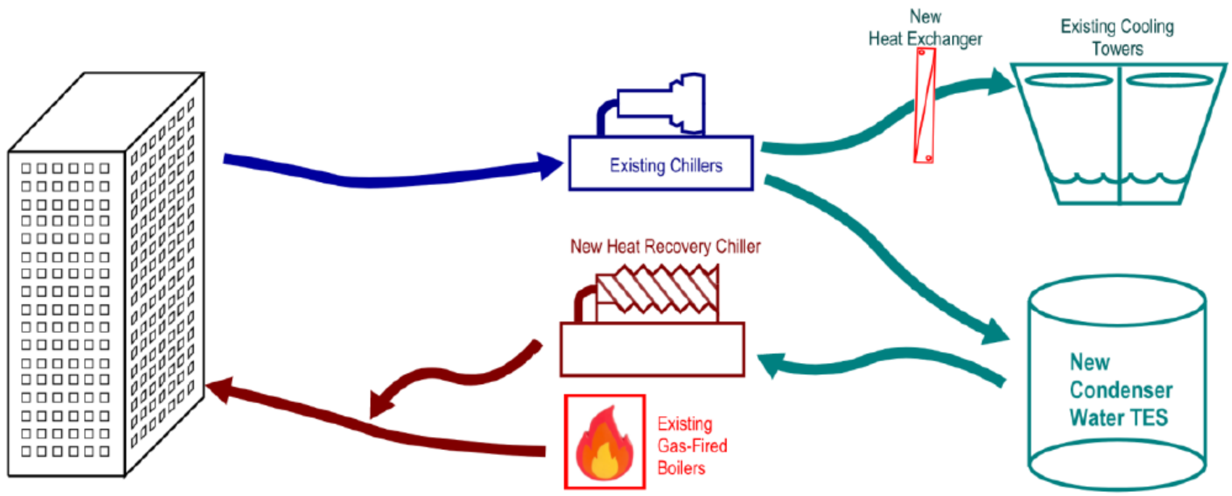

Figure 12. Schematic drawing of a heat recovery chiller and warm water storage tank added to an existing building with a boiler for heating and chiller for cooing. Source: *Stein and Gill 2024.*

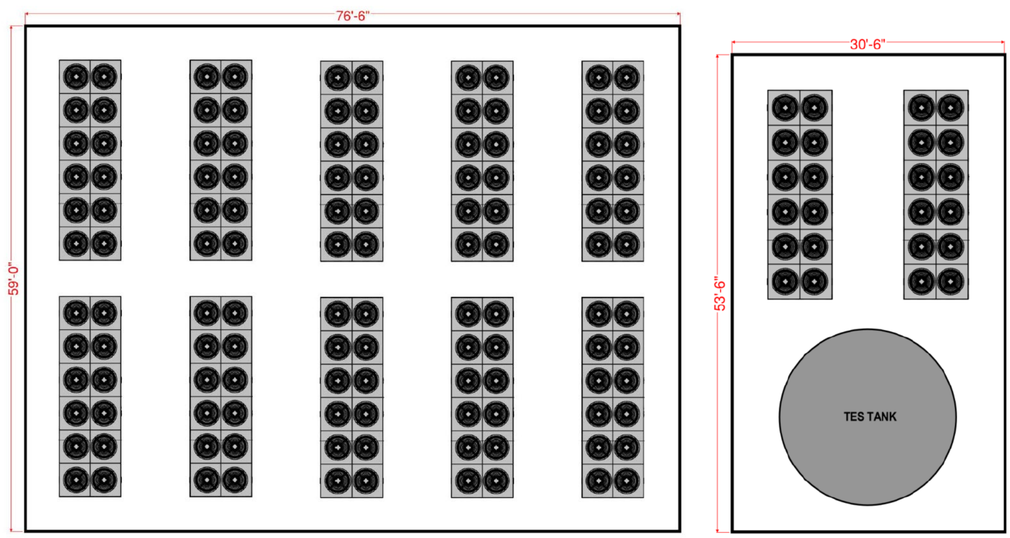

Figure 13. Illustrative footprint of air-source chiller system (left) and heat recovery chiller system with a storage tank (right). Source: *Stein and Gill 2024.*

We did not examine these systems in detail because they generally apply to the largest multifamily buildings with chilled water cooling systems, and costs and performance are very site specific. But these systems may be the best option in certain buildings. For example, the system shown in figure 12 was proposed for a San Diego building. In this application the new system was predicted to reduce space heating gas use by over 90% (Stein and Gill 2024).

Another heat recovery option is to use a heat pump loop, which involves installing heat pumps in individual apartments that operate off a loop that circulates warm water around the building, with water in the loop warmed by heat recovery from the hot-water system, and in summer, by heat given off by the heat pumps operating in cooling mode. This approach was used in the International Tailoring Building in NYC, a 180-unit multifamily cooperative. The existing heating and cooling systems were reaching end-of-life, so a new hydronic loop was installed, with heat pumps in individual apartments and a new condensing boiler. This system replaced noncondensing boilers, an absorption chiller, and fan coils in individual apartments. This expensive retrofit cost over $40,000 per apartment, with the new heat pump loop distribution system representing nearly half the cost. Yet this efficient system, with an estimated seasonal COP of 3.4, reduced gas consumption by over 70% and reduced site energy use by nearly 50% (B. Milbank, senior project development engineer, Ecosystem Energy, pers. comm., May 2025). Further information on the project is discussed by Building Energy Exchange (2024).

Ground-source heat pumps

Key takeaways

- Ground-source heat pumps are expensive systems but will often have higher efficiencies than the other systems examined in this report.
- Local site conditions will affect whether these are a viable option for a particular building.

Another option for some multifamily buildings is ground-source heat pumps. These may be served by groundwater from a well or wells drilled onsite, by a geothermal field of tubes spread out in a flat area adjacent to a building, or sometimes using water from a nearby pond. In these cases, the water or ground does not vary widely in temperature over a year and generally provides a higher temperature heat source than outdoor air for winter heating, increasing the heat pump efficiency. The various types of systems are illustrated in figure 14.

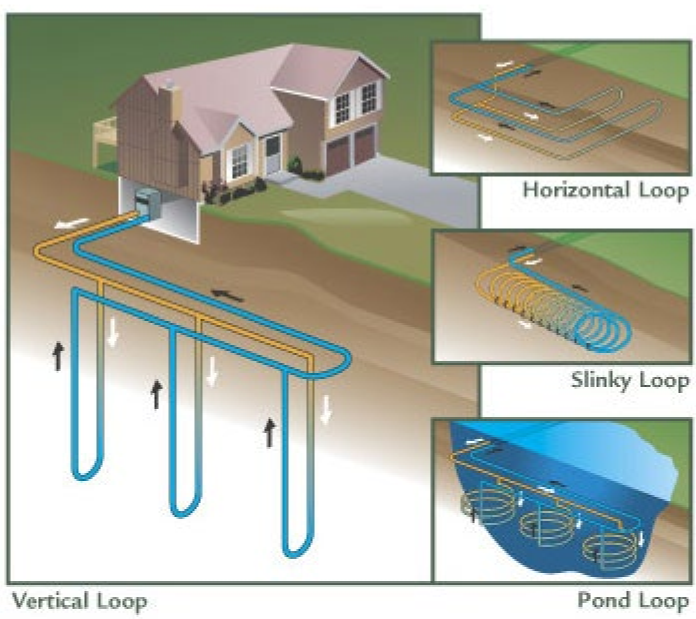

Figure 14. Illustration of types of loops that can be used for a ground-source system. Vertical wells can also be used.

For existing multifamily buildings, vertical loops or wells are much more likely as there is rarely open land next to existing buildings. For new buildings, horizontal loops can sometimes be put under parking lots or in open space. Ground-source systems can be costly due to the cost of the loop as well as the cost of the heat pump itself. Ground-source systems work best if annual heating and cooling loads are roughly balanced so that the ground temperature does not change a lot from year to year. Ground-source systems can have COPs of 3–6, reducing energy use substantially relative to air-source heat pumps. The typical ground-source system produces water temperatures of about 110–120°F (MassCEC 2025) and thus supplemental heat will generally be needed. But some systems can produce water as hot as 160°F (Rocky Ridge Geo 2025).

While these systems are generally higher efficiency than most of the other options discussed in this report (only heat recovery chillers have comparable efficiency), they are also more expensive. For example, a 2019 report estimates a cost of $30+ per square foot of floor area for these systems, compared to $2–20 per square foot for some of the other systems examined in this report (SWA 2019). In 2024$, the 2019 estimate is nearly $40,000 per apartment. These systems are also not possible in sites with large amounts of bedrock, with some types of soil, with underground utilities getting in the way, and where drilling equipment cannot gain access to the site.

An example of a multifamily building using ground-source heat pumps is SQ-Durlach project in Karlsruhe, Germany. This 30-unit apartment building was first constructed in 1963, and then renovated in 1995 to improve the building envelope and reduce heat demand. In 2022 a new heating system was installed to mostly replace the gas-fired boilers. The new system includes a ground-source system and an air-source chiller heat pump that operate in tandem. The combination system takes up less space and allowed a smaller borehole, reducing system costs. The system provides 98% of annual space heating energy and 45% of water heating energy (high required water temperatures limit the heat pump share for water heating) (Lammle et al. 2023).

Another example is the Terra Levis project in Levis, Quebec. The project, completed in 2020, installed 48 1-ton heat pumps, one per apartment, with these heat pumps connected to a geothermal circuit in the ground (Trane 2025).

Analysis approach

Our detailed analysis looks at each individual dwelling unit in the RECS 2020 dataset that aligns with our study's scope (multifamily buildings with five or more apartments that use a central system to heat multiple apartments). RECS includes detailed data on a representative sample of homes and apartments throughout the United States. For multifamily buildings, RECS collects and reports data at the apartment level, typically one apartment per building to represent the building. We conducted our analysis on space heating for each individual apartment in the RECS dataset within our scope, using apartment-specific energy use and costs. As discussed earlier in this report (in the section on the U.S. multifamily building stock), we assume each of these apartments uses hydronic heat, as it is rare to have more than five apartments on a single warm air system. Our general approach is to assume that new equipment is installed in 2030 and replaces existing equipment that has reached end-of-life. We look at the incremental cost of each system option relative to replacing the existing boiler. We use 2030 to allow time for many decarbonization policies to fully take effect and for equipment recently entering the market (e.g., window heat pumps, central air-to-water heat pumps, and new types of mini-splits) to become more established. We look at life-cycle costs for space heating, including the initial system cost and annual energy costs over the equipment's assumed 24-year life.[21] Who pays these costs—landlords or tenants—can be very important, as we discuss in the "Who Pays for Heat?" section below. But who pays for heat does not affect the basic life-cycle cost analysis.

Our analysis does not include tax credits or utility rebates. Costs incurred after 2030 are discounted back to 2030 using a 5% real discount rate. For energy costs, we focus on projected 2040 energy costs because 2040 is it roughly midway through the life of equipment installed in 2030. Our analysis looks only at direct equipment and energy costs and does not factor in societal costs such as health costs or impacts of climate change. These other costs can be difficult to quantify but should be considered in some fashion.

A total of 533 apartments are included in our dataset, selected to be representative of the 22% of apartments in buildings with five or more units, which is 15% of all apartments in the United States. We examine each apartment's energy use and costs in 2020 (the latter based on apartment-specific average gas and electric rates), and then adjust for projected changes in costs between 2020 and 2040 using national projections in the EIA's *2025 Annual Energy Outlook* (EIA 2025a). For natural gas we also include adjustments for distribution pipe replacement and for declining gas sales due to electrification, as explained in Appendix A. The costs and performance of the various types of heating systems are summarized below; these come from a variety of sources, primarily field studies on actual retrofits. In many cases these costs include electric system upgrades needed to accommodate new electric heating systems. For this study, we express these costs in 2024 dollars, adjusting for inflation using the implicit price deflator compiled by the Federal Reserve Bank of St. Louis (FRED 2025).

For each apartment, we look at the following low-carbon heating options:

1. Condensing boiler using alternative fuel, generally biomethane, but renewable diesel for apartments now heated by fuel oil and renewable propane for apartments now heated by propane[22]
2. Same as above but with higher gas utility distribution costs due to increased pipe replacement costs and to other customers leaving the system[23]
3. Mini-split heat pumps
4. Window heat pumps
5. Variable refrigerant flow (VRF) systems
6. Central air-to-water heat pump with electric resistance backup
7. Central air-to-water heat pump with alternative fuel (biomethane) provided via gas utility distribution system

[21] For window heat pumps, mini-splits, and VRF systems. we assume a 16-year average life and equipment replacement in year 16. Details are explained in Appendix A.

[22] Biomethane is a biogas, often produced in landfills or biogas digestors, that has been processed and cleaned to be chemically very similar to natural gas. It is sometimes called renewable natural gas (RNG). Renewable diesel is a biofuel that has been processed and cleaned to be chemically very similar to #2 fuel oil. Renewable propane is a synthetic fuel chemically similar to propane. Further information on these fuels is discussed in Traynor and Waite 2025.

[23] Specifically, as gas use declines due to electrification, gas rates will go up in order to recover fixed costs across the lower volume of sales. For these scenarios we included a 43% gas price increase based on the 50% electrification scenario examined by Nadel (2023a). This increase reflects the fact that fixed costs previously paid by former customers will now need to be paid by the remaining customers.

8. Same as above but with higher gas utility distribution costs due to increased pipe replacement costs and to other customers leaving the system
9. Air-to-water chiller using alternative fuel-fired backup (renewable propane or diesel[24]) served by on-site storage tank

The suitability and economics of heat recovery chillers and ground-source heat pumps for multifamily buildings are highly site specific, so we were not able to do a generic analysis using the available RECS data.

A summary of the cost and performance of the major systems is provided in table 7, drawing from the information in the sections above on individual equipment types.

Table 7. Typical cost and efficiency estimates for different system types

System type	Midpoint cost/apt.	Seasonal COP	COP at 17°F	Notes
Mini-splits	$16,435*	2.40	2.0	
Window heat pumps	9,300* (for 3 units)	2.56	2.51	1 HP/bedroom plus 1 for living room for cost;[25] avg. of Gradient and Midea for efficiency minus 10% for lower field performance
VRF	20,379*	1.60		
Condensing gas boiler	1,209**	0.90***	NA	
Oil boiler	1,377**	0.87***	NA	
Central air-to-water HP	13,359**	2.52***	1.7	Cost applicable only to buildings with current central hot water for space heating
Central air-to-water HP with gas utility backup	14,568**	2.52***	1.7	Sum of chiller and condensing boiler cost
Air-to-water chiller with electric resistance backup	13,964**	2.32***	1.7	Assume price midway between two rows above but efficiency 0.2 COP points lower
Air-to-water chiller with propane backup	15,016**	2.52***	1.7	Same as gas backup plus $450 for propane tank

*** These are costs for the initial system including average costs for upgrading onsite electric systems. For these systems, our analysis also includes a discounted cost for a replacement system in year 16.**

****For these systems we add $1,297 for three window air conditioners (less for small apartments, more for large apartments) since unlike the other systems, these systems usually need a separate system for cooling. These are initial costs as we assume these air conditioners need to**

[24] We use renewable propane for apartments now heated with propane and renewable diesel for apartments now heated with fuel oil.

[25] Place an extra heat pump for the living space in apartments 1,500 sq. ft. or more.

be replaced every 10 years. Neither initial nor replacement costs are included in this table, but are included in table 8, below.

***Seasonal COP is just for the boiler or chiller and does not include losses in the distribution system. Seasonable COP is generally based on field performance as discussed in earlier sections.

Note: Sources are discussed in the text above unless explained in the notes column. Propane tank cost based on $4,500 for a 1,000-gallon tank and assuming 100 gal./apt.

For central systems, such as boilers and chiller heat pumps, heat losses occur in the distribution system. These heat losses can be substantial, particularly in older buildings. We assumed that these losses are 25% of heating demand (Rose and Kragh 2017), which means that an additional 25% of heating capacity needs to be installed in order to get the correct amount of heat to individual apartments.

Options 1, 2, 7, and 8 include higher gas costs due to customers leaving the gas system. In 2023, ACEEE looked in detail at natural gas distribution systems (Nadel 2023), finding that costs could increase substantially in the future due to gas pipe replacement (often needed for aging systems in cities, particularly in the East) and electrification leaving fewer customers to cover fixed gas system costs. For options 1 and 7 we increased gas distribution costs by 13% for pipe replacement (based on a moderate gas pipe replacement program in Maryland) and used the 25% electrification scenario, with a distribution cost increase of 21%. These two adjustments increase the distribution cost by 37% (1.13*1.21). Options 2 and 8 represent higher distribution costs: We increased gas distribution costs by 39% for pipe replacement (based on an extensive pipe replacement program Philadelphia) and used the 50% electrification scenario, with a distribution cost increase of 43%. The distribution cost increases come from Nadel (2023). These two adjustments increase the distribution cost by 99% in the high distribution cost scenarios (1.39*1.43).

We recognize the great uncertainty about 2030 heating systems and 2040 energy prices, hence our results should be considered approximate. They are nonetheless useful for comparative purposes. In the “Sensitivity Analysis” section below, we include a few scenarios in which cost breakthroughs are achieved to reduce some specific heating system and energy costs that currently appear high. We also include some higher cost scenarios.

Results

Life-cycle costs

Our basic analysis is a life-cycle cost (LCC) analysis of each of the nine scenarios noted above over a 24-year analysis period.[26] The average LCC for all 533 apartments included in our dataset are summarized in table 8, ordered from lowest to highest. In general, window heat pumps on average have the lowest LCCs followed closely by the central air-to-water heat pump options and many of the boiler systems using biofuels (which is only a partial decarbonization option). Mini-splits on average have a slightly higher LCC, but given the wide range of mini-split costs and performance, in good applications mini-splits will be competitive with the options mentioned above. Our analysis finds that these four system types are likely to be the most cost-effective option for reducing carbon emissions in many multifamily

[26] Details on the analysis are explained in Appendix A.

buildings. Boilers using high-cost biofuels (high cost due to extensive gas pipe replacement and electrification) and VRF systems have somewhat higher LCC. The boiler options have low capital costs but high operating costs due to the expense of alternative fuels. The window and mini-split heat pumps have the lowest operating costs and medium capital costs. The central air-to-water heat pumps, on average, have lower capital costs but higher operating costs than mini-splits.

In general, many site-specific factors will affect the LCC of different systems and thus these results should be considered as a general guideline, but site-specific costs will need to be examined since site-specific results can vary from the findings of this generalized analysis.

Table 8. Average life-cycle cost (LCC) for the nine scenarios, net present value in 2024$, ordered from low to high

Scenario	Average LCC	Average capex	Avg. annual opex
Window heat pump	$14,474	$9,970	$266
Oil boiler using renewable diesel	20,831	3,399	1,029
Central air-to-water heat pump with electric resistance backup	21,898	15,938	352
Central air-to-water heat pump with gas boiler backup using biomethane	22,315	16,557	340
Central air-to-water heat pump with propane boiler backup using alternative fuel and including propane storage tank	22,665	16,992	335
Gas boiler using biomethane	22,902	3,179	1,165
Central air-to-water heat pump with gas boiler backup using high-cost biomethane	22,948	16,557	377
Mini-split	24,563	20,242	255
Gas boiler using biomethane and with higher distribution costs	31,574	3,179	1,677
VRF	31,581	25,100	383

Notes: Capex is capital expenditures and includes prorated replacement costs for equipment with a life of less than 24 years. Opex is operating expenditures. The small number of propane boilers are included with gas boilers in this analysis.

The lowest LCC is for the window heat pump systems due to their moderate capital cost and high efficiency. However, as noted above, these will not fit in all windows and some building owners may not like the aesthetics of these systems. The capital cost is based on projected costs over the medium term; current costs for pilot projects are often higher. The LCC is based on COP per laboratory tests plus a modest reduction for average field performance.

Next lowest LCC is the oil boiler using biodiesel. This is primarily an option for the limited number of boilers now burning oil. Oil is presently more expensive than natural gas, but by 2040 we estimate that gas prices will increase substantially due to the need to replace some aging gas pipes and reduced gas sales due to electrification.

The various central air-to-water heat pump options have slightly higher LCC; the cost assumptions here only apply to buildings that currently distribute hot water for space heating. All four of these options are grouped closely together with electric resistance backup and biomethane backup (medium-cost scenario) with similar LCC. Renewable propane with a storage tank is a little more expensive. In the case of electric resistance backup, our analysis does not include demand charges, which will apply to some multifamily buildings but not others. If there are significant demand charges, the biomethane backup may have a lower LCC. As with the other systems we examine, these LCCs include capital costs for heating and cooling but only heating operating costs are included. If a building already has central cooling, the central air-to-water heat pump can also provide cooling. But if central hydronic cooling is not installed but is desired, other options with cooling should be considered instead such as window, mini-split, and VRF heat pumps. These results for central air-to-water heat pumps are approximate as the costs are based on three projects and the performance based on a single project. As more data become available, some of these assumptions may need to change.

The gas boiler with moderate distribution costs and burning biomethane comes next in average LCC. This option still releases carbon when the gas is burned but some of these emissions are offset when plants are grown to produce the biomethane (Traynor and Waite 2025).

The mini-split has the next lowest LCC based on our assumptions. This option has low operating costs as distribution losses in the short refrigerant lines are often modest, and it provides both heating and cooling (our LCC only includes heating). However, as discussed above, individual projects have been both less and more expensive than the average value we use in this analysis. While all systems will vary in cost and performance from site to site, the mini-split seems to vary more widely than the other options.

The gas boiler burning biomethane but with high gas distribution costs and the VRF system have the highest average LCC, substantially higher than the mini-split. The VRF system has the highest capital cost of the options examined but operating costs only a little higher than the central air-to-water heat pump. The boilers using alternative fuels have low capital costs but high operating costs, particularly if we include substantial costs for pipe replacement and other customers leaving the gas system.

While this analysis provides averages for the entire country, we also examined how climate (as measured by heating degree days) and apartment size affect LCC. Higher heating degree days and larger apartments modestly increase LCC. These results are illustrated in Appendix B.

Economics relative to fossil fuels

Total heating energy costs are dependent on local utility prices for electricity and displaced fuels; for buildings on commercial rates, there are often charges for the maximum level of electricity demand. On average, apartments in our dataset had an annual energy bill for space heating of about $311.[27] As shown in table 8, annual operating costs for the window and mini-split heat pumps are lower than this fuel average, although they have much higher capital costs than boilers. If air-conditioning needs to be installed, the window and mini-split heat pumps can be a way to add air-conditioning while reducing space heating operating costs.

[27] This is for the average existing system. Many of these are noncondensing boilers. We calculated this figure from 2020 consumption and energy costs for each apartment in our database to derive an average volumetric energy cost plus an adjustment for changes in energy prices between 2020 and 2024. We did not have sufficient information on each apartment to separate energy and demand charges. Details are explained in Appendix A.

Electricity prices are generally higher per Btu than those of natural gas, though they are lower than fuel oil or propane prices. At the national average commercial electricity price of $0.1285 per kWh in 2024 (EIA 2025b), and assuming an average seasonal heat pump COP of 2.5, electricity still costs about $15.06 per million Btu of heat supplied, which is substantially less than the cost of biomethane (over $30 per million Btu retail, see Appendix A) but more than the average $10.83 per million Btu for a boiler, assuming the average commercial retail natural gas price in 2024 ($9.75 per million Btu; EIA 2025c) and a boiler efficiency of 90%.

Electrifying multifamily buildings is expensive. Our heat pump options begin at $9,300 per apartment. Even if we subtract gas boiler replacement costs of $1,200–1,400 per apartment, this is substantially more than the incremental cost to electrify many single-family homes (which is on the order of $4,600 for replacing a warm-air furnace when the existing system needs to be replaced; Nadel and Fadali 2024). Furthermore, single-family homes on average use substantially more energy, increasing the value of energy savings from high-efficiency systems.

We discuss some possible options to address these economic challenges in the “Program and Policy Options” section later in this report.

Impact of energy efficiency on life-cycle cost

As part of our analysis, we also looked at energy efficiency retrofits on buildings to reduce energy use and loads. Specifically, for this analysis we looked at a moderate efficiency package based on the Energy Savers program operated by Elevate Energy in Chicago. Typical packages include roof insulation, air sealing, new properly sized boiler and controls, and lighting improvements. More than 11,000 units have received efficiency packages, at an average cost of about $2,200 per apartment (Farley and Ruch 2013), achieving an average of approximately 26% heating season energy savings (Navigant 2013). Adjusting the cost for inflation, since 2013, the 2024 cost will be about $2,909 per apartment.

We applied these costs and savings to each apartment in our database and further assumed that the efficiency package reduces the cost of the new heating system by 10%, since with reduced heating loads, a smaller system can be installed. We then looked at the LCC net benefits of such a package using a 24-year measure life and a 5% real discount rate. We found that there are average net benefits of $2,630 applying the efficiency package to gas boilers using biomethane, and net benefits of $4,885 for the efficiency package in gas boiler homes paying a higher price for biomethane. Likewise, for oil boilers using biofuels, the net benefits of the efficiency package are $2,052. But for many of the heat pump scenarios, energy bills are modest and so 26% savings are not worth very much, resulting in very small net benefits. The one exception is for VRF systems, where the 10% reduction in system costs plus a 26% reduction in operating costs results in average net benefits of $1,577.

Looked at in terms of simple payback period, the energy efficiency package had an average simple payback period of 8.2 years in apartments with gas boilers using biomethane and 5.7 years using biomethane with higher gas distribution costs. For apartments with VRF, a 10% savings on system costs almost covers the cost of the efficiency package, resulting in a simple payback of 1.1 years. For mini-split systems, the average simple payback of the efficiency package is 9.0 years, but for other systems, the simple payback is over 10 years. That said, reasons to pursue efficiency beyond direct energy bill savings include reducing peak power demand, limiting the need for backup heat, and improving resident comfort. We discuss these issues in the “Discussion” section later in this report.

If instead of looking at the simple payback for all apartments, we only look at apartments with above-average energy use, then the simple payback improves to 6.2 years with mini-split systems and approximately 9.0 years with the chiller systems. The modest improvement from looking at only high energy users is due to the low energy use of most of these apartments.

Sensitivity analyses

In addition to our main analysis, we also prepared a variety of sensitivities. Table 9 summarizes the LCC of the main analysis and each of the alternative analyses. In general, if just a single option has lower or higher capex, its relative position on LCC changes. For example, if mini-splits are 25% less expensive than in our base case, their average LCC is lower than all but the window heat pump base case option. If biomethane costs are 25% lower than our base case, then the boiler with biomethane option has a lower LCC than all but the window heat pump. A higher VRF COP reduces its average LCC, but not enough to change its relative position.

Table 9. Sensitivity analysis LCC results

Scenario	Base	High capex	Low capex	High biomethane cost	Low biomethane cost	High VRF COP
Window heat pump	$14,474	$16,966	$11,981			
Central air-to-water HP with electric resistance backup	21,898	25,389	18,407			
Central air-to-water HP with gas boiler backup using biomethane	22,315	25,962	18,668	$22,664	$21,966	
Central air-to-water HP with propane boiler backup using alternative fuel including storage tank	22,665	26,420	18,911			
Mini-split	24,563	29,623	19,502			
VRF	31,581	37,856	25,306			$30,285
Gas boiler using biomethane	22,902	23,204	22,600	27,680	18,124	
Oil boiler using renewable diesel	20,831	21,175	20,487			
Gas boiler using high-cost biomethane	31,574	31,876	31,272	38,520	24,628	

Note: Blank cells indicate that a specific alternative scenario does not apply to an option.

Discussion

A number of issues that cut across the various scenarios merit exploration. In the following sections we discuss some of these issues:

1. Electrical upgrades
2. Availability of biomethane and other biofuels
3. Is backup heat needed?
4. Role of energy efficiency
5. Need for qualified contractors
6. Who pays for heat?
7. Need for more project experience

Electrical upgrades

For older buildings that were designed for modest electrical loads, adding heat pumps will often require increasing the amount of electric service in a building, which means new electric panels and sometimes a new electric supply cable from the utility. Zuluaga estimates that buildings built prior to 1946 will need electric upgrades if they have not been previously upgraded, adding about 15% to project costs (M. Zuluaga, cofounder and chief revenue officer, Cadence OneFive, pers. comm., January 2025). Costs are highly site specific. For example, AEA provided us cost data on some of their projects in New York City, with the majority needing electrical upgrades. Where electric upgrade costs were broken out, they ranged from about $1,000–4,000 per apartment (Asit Patel, ANP Energy Consulting Services Corp., pers. comm., January 2025). In some cases, the electrical upgrade costs can be even higher. For example, for the International Tailoring Building discussed in the heat recovery chiller section, electrical upgrade costs were about $8,000 per apartment (B. Milbank, senior project development engineer, Ecosystem Energy. pers. comm., May 2025).

Furthermore, if the utility needs to run a new cable and they are busy, we have heard about project delays of many months.

On the other hand, one commenter on a draft of this report noted that the National Electrical Code (NEC) essentially assumes that if there are multiple heat pumps in a building, they all operate at the same time and that these loads are fully coincident with all other building loads. This comment suggested further study on these assumptions. If coincidence factors prove to be less than 100%, perhaps the NEC could be amended based on this data and less upgrades would be needed. Such a process would be a long-term effort, taking many years for research and then consideration of proposals to change the NEC.

Availability of biomethane and other biofuels

Biomethane and other biofuels are in limited supply, and residential space heating is unlikely to be the most important or cost-effective use of limited biofuel quantities. Even optimistic estimates of future biomethane supply are insufficient to replace natural gas use across all sectors, even if we just consider those end uses that are especially hard to decarbonize. Demand in these hard-to-decarbonize sectors, such as aviation or high-temperature industrial processes, could create competition for biomethane supplies across sectors and limit the availability for use in buildings, where electrification is a feasible option in most cases. Traynor and Waite (2025) discuss this issue extensively, and we do not repeat that discussion here.

Is backup heat needed?

Cold climate window, mini-split, and VRF systems can commonly operate down to temperatures of around −10°F and sometimes even colder. Heat output goes down as temperatures drop, but if sized for the load, no backup is needed with these systems down to temperatures of around −10° F. In colder climates, some backup heat will be needed; this could be electric resistance or some type of fuel. As cold climate heat pumps improve in performance, this temperature threshold may decline.

However, sizing a window, mini-split, or VRF system to meet the full load at very cold temperatures increases system costs and results in operation at part load for much of the year. Some owners prefer partial electrification in order to reduce system capital costs, using the existing boiler to supplement the heat pump. Furthermore, some electrification programs report that contractors and code inspectors may prefer to have a nonelectric backup system to avoid having to fully trust an all-electric system, to mitigate the need for electrical upgrades, to reduce loads during winter peaks, and to limit the perceived chances of emergency calls. If existing boilers are in place and functioning, many projects leave the boilers in place as a backup, sizing the heat pumps to meet on the order of 80% of the annual heating load (N., Ceci, principal mechanical engineer, Steven Winter Associates, pers. comm., June 2025). This leaves the question of what to do when the existing boiler reaches end-of-life, but by then further weatherization improvements can be made to the building, new heat pump or backup heating options may be available, and at a minimum, a new smaller boiler can be installed, assuming gas service remains available.[28]

For central air-to-water heat pump systems, the existing hot-water distribution system is generally designed for 160–180°F water temperatures but the heat pumps typically only heat water to 140°F. Supplemental heat will be needed on cold days to raise the distribution water temperature to 160–180°F. Alternatively, new distribution systems can be installed designed for 140°F water, but this substantially raises retrofit costs.

A common source of backup heat is electric resistance, but such a backup will contribute to winter peaks and potentially high demand charges. Energy efficiency improvements to buildings can reduce these peak loads. Another option that might be worth exploring to reduce winter peaks is heat storage (Hill 2025), although storage must be long term for prolonged cold spells. But in order to minimize contributions to winter peaks, some buildings will retain a fuel backup.

Role of energy efficiency

Energy efficiency improvements to buildings can reduce heating loads, allowing smaller systems to be installed, reducing winter peak electric demand, and improving resident comfort. But weatherization of multifamily buildings, many of which are built with brick, can be expensive. Our earlier analysis, summarized in a prior section, found that energy efficiency measures can be cost effective with gas and oil boilers and VRF systems, but while there are life-cycle cost savings for other system types, payback periods are long.

This analysis is based on current electric rates plus a 1% increase in electricity prices due to electrification (discussed in Appendix A). Areas that expect to become winter peaking may have greater

[28] Some utilities, cities, and states are looking to decommission aging gas lines instead of replacing them, but with only limited exceptions, such gas line retirements are likely more than a decade away.

reason to encourage energy efficiency improvements to buildings, either before heat pumps are installed, or to eventually displace backup boilers. Many affordable housing developers we interviewed for our research emphasized the importance of "weatherization first" in order to ensure that heating bills are affordable following electrification. Likewise, in May 2025, the New York Public Service Commission ruled that:

> As we look ahead to the 2026–2030 program period and better understand the significant implications building electrification at scale will have on our electric grid, we must now require programs that are encouraging building electrification to do so in ways that are in line with mitigating these future costs. Therefore, the NYS Clean Heat Program [a major electrification program in the state] needs to evolve rapidly to drive most projects to meet an established minimum weatherization level, with significantly differentiated incentives for heat pump projects that do not meet this weatherization level.… The Commission recognizes that building weatherization at scale may be more expensive on a saved energy unit cost basis than other measures, including building electrification, but improving the envelope efficiency of the existing building stock before electrifying is critical to manage eventual winter peaks when larger portions of the State's building stock electrify to meet State policy goals (NYDPS 2025).

Other cold-weather states that expect to become winter peaking should consider similar strategies.

Need for qualified contractors and maintenance staff

Multifamily heat pump installations are often complicated and require proper installation and commissioning to work properly. This is particularly true for VRF systems, but also applies to mini-split and central air-to-water heat pump systems. VRF systems require complex electrical work, refrigerant charging, and integration with existing building systems, making proper training for installers critical to optimize performance. Improper installation can lead to inefficient operation, increased energy consumption, and equipment failure. Experienced staff can also complete work more quickly than inexperienced staff, often reducing costs.

The expanding market for heat pump technologies in the multifamily sector means a growing need for experienced contractors who can provide on-the-job training to less experienced installers. Furthermore, these systems require ongoing maintenance, and many repairs require a qualified contractor or building maintenance staff trained in refrigerant systems and electrical systems (Building Energy Exchange 2021).

Currently, there is a shortage of training programs and technical resources for reliably installing, operating, and maintaining these systems in multifamily buildings (Srivastava, Aquino, and Ayala 2025). Addressing these gaps in training and workforce development will be crucial to long-term decarbonization.

Who pays for heat?

When evaluating systems for decarbonization, considering billing and metering configurations early in the process is critical. Factors such as billing structures and affordability requirements can affect system selection, and failure to consider these issues at the start may lead to challenges during planning or after installation.

This is particularly important in rental apartment buildings where, prior to the retrofit, the owner paid for heating and tenants paid for cooling, as electrification may require a change in metering and payment structure. In states such as New York and Massachusetts that are investing heavily in electrification, policymakers want to ensure that electrification does not result in increased costs for low- and moderate-income renters.

To help put these issues in perspective, some metering and payment options and their challenges are presented in the table 10.

Table 10. Post-retrofit metering options for rental buildings with owner-paid heating and tenant-paid cooling prior to heat pump retrofit

Heat pump metering options (post-retrofit)	Who pays for heating	Who pays for cooling	Considerations
Option 1: Heat pumps go on owner's meter	Owner	Owner	Owner assumes cooling costs Increases operating budget or rent (often not viable in affordable housing)
Option 2: Heat pumps go on owner's meter; tenants are submetered for cooling	Owner	Tenant	Owner bills tenant for cooling Logistically challenging Submeter installation adds cost May require third-party billing
Option 3: Heat pumps go on tenant meter	Tenant	Tenant	May be prohibited in affordable housing where submetering may not be allowed Even where not currently prohibited, policymakers may object and consider changes to policy May face resistance from market-rate tenants unaccustomed to paying for heat
Option 4: Heat pumps go on owner's meter; owner does not provide cooling function	Owner	Tenant	Cooling mode can be disabled on some heat pump models Requires tenants to install their own, often less efficient equipment

For owners who prefer not to cover cooling costs, submetering tenants may be an option, but it comes with significant challenges. In affordable housing, for instance, tenants enrolled in utility assistance programs tied to specific fuel types may face adjustments or require regulatory approval if the metering configuration changes (Francisco et al. 2022). Additionally, state and local regulations often impose strict requirements on submetering electricity. In New York City, for example, buildings must uphold consumer protections, including transparent billing mechanisms and a formal dispute resolution process (NYSDPS 2024).

Additional factors to consider include variations in rate structures and utility costs, as electricity rates on a master meter can differ significantly from those on individual apartment meters. While owners may benefit from potential savings, some jurisdictions, such as New York City and Chula Vista, California, require these savings to be passed on to tenants. Furthermore, demand charges can affect overall costs, adding another layer of financial complexity.

To effectively assess decarbonization options for multifamily retrofits, it is essential to address these technical, legal, and regulatory considerations early in the planning process, ensuring a fair and sustainable transition to electrified systems. There is no preferred solution, as the optimal solution will vary with the current situation and local laws.

Need for More Project Experience

Many of the system options discussed in this report only have a few dozen multifamily installations across the United States. And some systems such as window heat pumps and chiller heat pumps have thus far been used in just a few multifamily buildings. Much more experience is needed to improve performance, better understand ways to reduce costs and installation challenges, and understand what constitutes a good level of performance (e.g., seasonal COP) for each type of system. Affordable housing organizations, owners interested in the environment, states, localities, and utilities should step up their efforts to implement all of these system options and thereby contribute to an understanding of best practices for different types of buildings. Further field studies are needed to evaluate performance claims and establish best practices and guidance on feasibility for different building types, climates, and existing conditions.

Program and policy options and recommendations

In order to further the decarbonization of space heating in multifamily buildings, a number of steps should be taken, including:

- Training programs on proper installation and repair for each type of system; manufacturers, states, and localities can lead such efforts.
- Increased number of demonstration programs and pilot programs in order to grow experience with each of these systems; states, utilities, localities, and affordable housing organizations can lead these efforts.
- In some cases, codes and laws may need modification to permit good decarbonization options to move forward. For example, in Illinois, the administrative code (83 Ill. Adm. Code 410.130(a)) requires separate metering of electrical energy use. Central gas systems have no requirement for individual metering, but electrical systems would, even if a project uses a central system or in-unit mini-splits powered from an owner-paid electrical meter. To install central systems, a complaint must be filed for an order waiving the separate metering requirements. This lengthy process has no guarantee of success. Laws like this may need changing to permit owner-paid electric heat, such as central VRF and air-to-water heat pump systems in appropriate applications.

The economics of switching from fossil fuels to heat pumps or alternative fuels are often challenging. Policies to address these challenges should be considered, including

- Offer special rates for heat pumps based on cost of service: In many cases, heat pump customers are charged more than the cost of service and effectively subsidize other customers. These issues are discussed in recent reports by RMI and ACEEE (Shea, Dammel, and Fink 2025; Sussman et al. 2025; Yim and Subramanian 2023).
- Put a price on carbon emissions so that carbon emitters such as buildings burning oil, propane, and natural gas pay for the social cost of these emissions. Such pricing is widespread in Europe and is now used in some Canadian provinces, California, and Washington (Nadel, Gaede, and Haley 2021), with regulations being developed for programs in New York (NYS 2025) and Oregon (2025).

- Incentive programs can help pay some of the installation cost of low emission systems, particularly for buildings with affordable rents. Funds can come from utility rates and/or tax revenues, including from carbon emissions fees. One program that can be tapped is the Home Energy Rebate program, which is funded by the federal government but operated by individual states; this includes rebates per apartment up to $14,000 (BPA and AnDyl 2025).
- Financing programs can complement incentives and help building owners pay for these new low-emission systems. Some examples are discussed by Mah, Farrell, and Sussman (2025).
- Continued research, development, and demonstrations can explore ways to lower the installed cost of heat pump systems. Also, further research is needed on approaches for transitioning away from backup boilers when existing boilers need replacement.

In addition to programs targeting decarbonization economics, broader policies to promote and require decarbonization should also be pursued. Examples include:

- Building performance standards are now used in four states and 10 cities to require reaching specified energy-saving or decarbonization targets over a series of years (Nadel and Hinge 2023; IMT 2025).
- Clean heat standards require natural gas utilities and fuel dealers to gradually reduce their greenhouse gas emissions over time through methane leak reduction, electrification of buildings, use of biomethane, and other measures (Santini et al. 2024).
- Zero emissions heating standards require new systems being installed to be zero emission. The San Francisco Bay Area has adopted such a policy and states such as California and Maryland are considering such policies (Levin, Louis-Prescott, and Breit 2024).

Conclusions and next Steps

Dozens of completed projects, including some of the case studies noted in this report, indicate that existing multifamily buildings can be converted to heat pumps, but that projects can face significant challenges and costs. Our analysis suggests that window heat pumps generally have the lowest life-cycle costs, but these systems will not be appropriate for some applications. Other electric decarbonization options for multifamily buildings, in order of increasing life-cycle cost, are central air-to-water heat pumps, mini-split heat pumps, and VRF systems. Boilers using biofuels (a less than full-decarbonization option) typically have life-cycle costs between window heat pumps and mini-split systems. Each building will have unique opportunities, but our analysis indicates a potential order in which options might be investigated. In most cases, the three full (or nearly full) decarbonization options with the lowest life-cycle costs (window, central air-to-water, and mini-split heat pumps) should be considered, with the best choice often based on building-specific characteristics.

While dozens of buildings have been converted, the economics are challenging due to the high cost of converting to heat pumps; fossil fuel systems will often be lower capital cost than any of the decarbonization options we examined.

Program and policy options to improve decarbonization economics should be pursued, including additional demonstration projects (particularly window, mono-block like the Ephoca system, and central air-to-water heat pumps), heat pump electric rates based on the cost of service, putting a price on carbon emissions to reflect the impacts of fossil fuel combustion, incentive and financing programs (potentially financed with carbon price revenues), and identifying and addressing code barriers.

In addition to pursuing these program and policy options, other near-term steps should include expanding efforts to train contractors on best practice installation and repair techniques and additional demonstration programs to build up experience and further identify best practices.

Existing multifamily buildings can be decarbonized, contributing to reduced emissions and efforts to slow climate change. There has been substantial progress in recent years improving system options, developing new approaches (e.g., window, central air-to-water, and mono-block heat pumps), and learning what works and what does not. These efforts should be accelerated.

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Appendix A. Methodology

The "Analysis Approach" section in the main report describes our general methodology. Here, we provide additional details regarding the following:

- Annual energy use
- Equipment and installation costs
- Equipment performance
- Electricity prices
- Fuel prices

Annual energy use

For each apartment we take the 2020 energy use for space heating from the 2020 Residential Energy Consumption Survey (RECS). We only look at space heating energy use and not other uses.

Equipment and installation costs

We estimated equipment and installation costs from a variety of published sources as discussed in the text on each system type and summarized in table 7. We use 2024$ as a common denominator, adjusting data from other years using the GDP Implicit Price Deflator published by the Federal Reserve Bank (FRED 2025). These are our estimated midpoint costs used in our primary analysis. In the main report we discuss a variety of sensitivity analyses with lower and higher costs.

Our analysis period is 24 years, based on the approximate average lifespan of chillers and boilers (ASHRAE 2022). For mini-splits and VRF, often a 15-year life is estimated (e.g., similar to unitary equipment; ASHRAE 2022), sometimes a little more. For window heat pumps, the NYCHA Request for Proposals for a bulk purchase requested a 20-year life and the compressor is warrantied for 12 years. Based on these different data points, we use a 16-year life in our analysis of mini-splits, VRF, and window heat pumps and assume that a replacement unit is purchased in year 16. We discount this purchase based on a 5% per year real discount rate, and then divide by two to capture only eight years of life, equaling our 24-year analysis period. Given these assumptions, the replacement unit adds 23.16% to the initial cost of units with a 16-year average life.

Most of our systems provide both heating and cooling, but the boilers are heating only, and the central air-to-water heat pumps provide cooling only if fan coils are installed in each apartment, which is expensive and infrequently done. Therefore, to include at least basic cooling with these options, we assume room air conditioners are used, with a 10-year life (U.S. Department of Energy 2023b) and units replaced in years 10 and 20. For the latter replacement we take 40% of the cost for the four years of life covered in our 24-year analysis. For the replacements, costs are discounted back to the present using a 5% per year real discount rate. For the room air conditioners, we use the same number of units as with window heat pumps: one per bedroom, one for the living room, and an additional unit for apartments 1,500 sq. ft. or more.

Equipment performance

Average seasonal equipment efficiencies are discussed in the text for each system type and summarized in table 2. For the electric heat pump options, seasonal efficiency will vary with climate, with efficiencies higher in warm climates and lower in cold climates. To adjust for this factor, we used a regression equation for commercial heat pumps developed by Nadel and Perry (2020) as shown in figure A1.

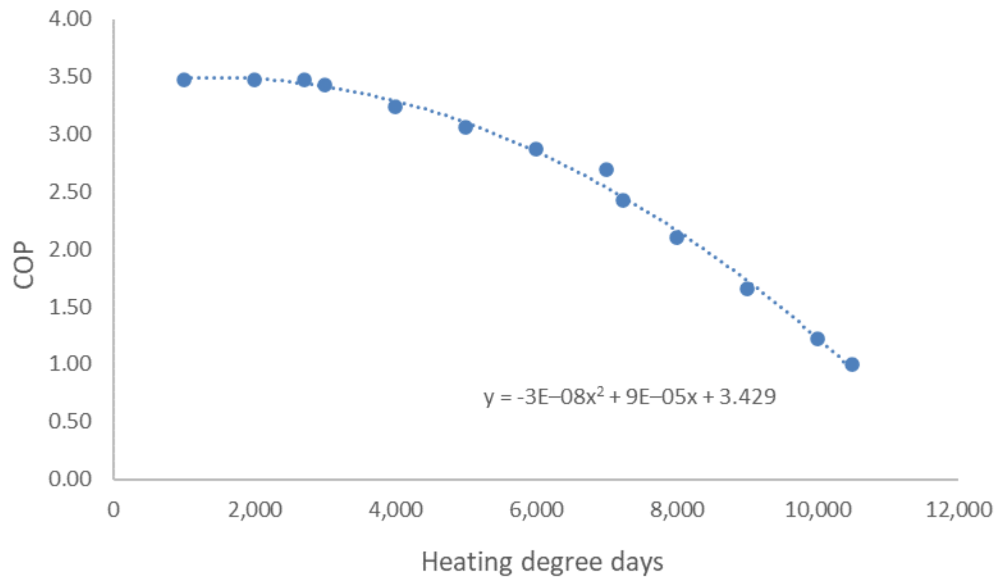

Figure A1. Seasonal COP as a function of heating degree days. This particular curve is for equipment with a national average seasonal COP of 2.835. For each type of equipment, we multiplied the COP from this formula by the seasonal COP for that type of equipment as shown in table 2 and then divided by 2.835. Source: Nadel and Perry 2020.

Electricity prices

We start with electricity prices for all end uses in 2020 as paid by each apartment in the RECS dataset. This allows us to capture utility-specific and apartment-specific effects. We take total electricity bills and divide by annual kWh consumption, resulting in average annual cost per kWh. For our main analysis, we add an adjustment for the average national commercial electricity price in 2040[29] relative to the national average commercial price in 2020. This adjustment multiplier is based on the Reference Case forecast in EIA's *2025 Annual Energy Outlook* (EIA 2025a). We also add an adjustment to reflect the increase in electricity prices from high levels of electrification. This multiplier is based on a comparison between reference and high electrification scenarios in NREL's Electrification Futures Study (Murphy et al. 2021).

In reality, many multifamily buildings have their central loads on commercial rates, which often include a demand charge based on the maximum facility hourly electricity use in a month or even in the year. We did not have customer-specific data on demand charges and thus were not able to incorporate them in our analysis. To the extent there are demand charges, they are incorporated in the per-kWh electricity prices we use. If demand is charged separately, then the variable kWh charge would be lower than we use, improving heat pump economics to the extent the heat pumps do not increase peak demand.

Whether building demand peaks coincide with grid peaks depends on how each utility structures its demand charges. In much of the country, peak electricity use is on hot days, and heating energy use does not have a direct impact on peak demand. But switching to a heat pump often adds the ability to provide cooling, which does affect hot weather peaks. Furthermore, much of the country is projected to

[29] We use 2040 as it is approximately midway into the life of equipment first installed in 2030.

become winter peaking in the 2030s or 2040s.[30] Electric resistance heat uses the most electricity on cold days, heat pumps use a medium amount on cold days, and gas systems generally use the least electricity on cold days. Given these complexities, the impact of demand charges on heat pump economics will be highly variable, with site-specific impacts depending on the specific building and system, how cold it is, the backup heating system, and individual utility rate structures. But if demand charges are based on electricity use on cold winter days (e.g., for a winter-peaking utility), use of heat pumps will affect demand changes.

Table A1. Electricity prices

Item	Amount	Source	Cite
2020 average (2020$)	$0.1068	EIA Electricity Monthly	EIA 2025a
2020 average (2024$)	$0.1276	Adjusted with GDP deflator	
2024 average (in 2024$)	$0.1285	EIA Electricity Monthly	EIA 2025a
2040 average (in 2024$)	$0.1154	2040 forecast from AEO 2025	EIA 2025a
Multiplier from 2020 price	0.914		
Multiplier to account for a high electrification scenario	1.01	EFS Base Case High Electrification scenario compared to EFS Base Case Reference Electrification scenario	Murphy et al. 2021

Fuel prices

For natural gas, we also start with 2020 prices for all end uses as paid by each apartment; we then add a multiplier based on the projected increase in the national average commercial natural gas price, comparing 2020 average price (EIA 2025c) and projections for 2040 (EIA 2025a).

Next, we adjust for the use of biomethane to substantially reduce carbon emissions by separating the rates into two components: variable fuel cost and the fuel distribution cost. We adjust for the use of biomethane as a fuel, using estimates of the wholesale price of biomethane. This comes from the average of two studies: a study by the consulting firm E3 for Massachusetts Department of Public Utilities (E3 2022) and a study prepared by ICF (2022) for NYSERDA. Biomethane increases the cost of fuel but does not affect the gas distribution cost.

For the distribution cost, we take the estimated 2040 commercial gas distribution costs from Traynor and Waite (2025), which were based on a comparison of 2040 wholesale and retail prices in 2040, from the Annual Energy Outlook 2023 (EIA 2023b). We then make two adjustments to the total price, based on factors that are likely to increase distribution costs. First, we add 13% to account for a moderate amount of replacement of aging gas pipes. Multifamily buildings are often in cities with aging gas infrastructure that needs to be replaced. The 13% adder is based on Maryland, as discussed by Nadel (2023). In places such as Boston, NYC, and Philadelphia, this adder is probably more, and so for the high biomethane cost scenarios we instead increase the distribution portion of rates by 39%, which is based

[30] For example, the New York Independent System Operator projects that New York State will become winter peaking in 2027 (NYISO 2024).

on Philadelphia Gas Works (Nadel 2023). Second, we assume that by 2040, 25% of gas end uses are electrified, with the costs of gas distribution moved to remaining customers. Multifamily buildings are often located in cities and states that are seeking to promote electrification, and thus this 25% estimate is quite likely conservative (in our high distribution cost scenario analysis, we look at 50% electrification). For 25% electrification we add 21% to distribution costs; for 50% electrification we add 43%. Both adders come from Nadel (2023).

Data and calculations are shown in table A2.

Table A2. Natural gas prices

Item	Amount	Source	Cite
2020 average commercial retail price (2020$)	$8.79/MCF	EIA Natural Gas Monthly	EIA 2025c
2020 average (2024$)	$10.50/MCF	Adjusted with GDP deflator	
2024 average (in 2024$)	$10.12/MCF	EIA Natural Gas Monthly	EIA 2025c
2024 average (in 2024$)	$9.75/therm	Based on 1038 Btu/CF	
2040 average (in 2024$)	$10.10/MCF	2040 forecast from AEO 2025	EIA 2025a
Multiplier from 2020 price	0.962		
Wholesale price of NG 2040	$4.27	AEO 2025	EIA 2025a
Wholesale price of biomethane 2040	$27.00	Average of E3 and ICF values	E3 2022, ICF 2022
2040 commercial distribution cost	$3.50	Based on Traynor and Waite 2025, estimated from 2040 gas prices in EIA 2023c	Traynor and Waite 2025, EIA 2023b
2040 biomethane commercial retail price	$30.50	Sum of wholesale price of biomethane and commercial distribution cost	
Multiplier for biomethane costs	2.90	Ratio of total commercial retail price of biomethane in 2040 to 2020 retail natural gas price	
Increase due to customer electrification (base)	21%		Nadel 2023
Increase due to customer electrification (high)	43%		Nadel 2023
Increase due to pipeline replacements (base)	13%		Nadel 2023

Item	Amount	Source	Cite
Increase due to pipeline replacements (high)	39%		Nadel 2023

Similarly, for fuel oil and propane we start with 2020 prices for all end uses as paid by each apartment; we then add multipliers to each based on the projected increases in the national average fuel oil and propane prices between 2020 and 2040. Next, we adjust for the use of renewable diesel to reduce carbon emissions associated with fuel oil, and renewable propane for fossil propane. We use the same multiplier as for biomethane prices and apply this to the fuel oil and propane prices. We also add 10% for increased delivery costs (a conservative guess) due to declining oil and propane sales and thus longer travel times per delivery.

Table A3. Fuel oil prices

Item	Amount	Source	Cite
2020 average (2020$)	$2.93/gal.	EIA Weekly Heating Oil and Propane Prices	EIA 2025d
2020 average (2024$)	$3.50/gal.	Adjusted with GDP deflator	
2024 average (in 2024$)	$3.73/gal.	EIA Weekly Heating Oil and Propane Prices	EIA 2025d
2040 average (in 2024$)	$3.24/gal.	AEO (EIA 2025a)	EIA 2025a
Multiplier from 2020 price	0.93		
Multiplier for increased delivery costs from decrease in fuel oil customers	1.10	Assume 10% increase	
Total multiplier	1.02		

Table A4. Propane

Item	Amount	Source	Cite
2020 average (2020$)	$1.95/Btu	EIA Weekly Heating Oil and Propane Prices	EIA 2025d
2020 average (2024$)	$2.33/Btu	Adjusted with GDP deflator	
2024 average (in 2024$)	$2.50/Btu	EIA Weekly Heating Oil and Propane Prices	EIA 2025d
2040 average (in 2024$)	$2.23/Btu	AEO (EIA 2025a)	EIA 2025a
Multiplier from 2020 price	0.93		

Appendix B. Life-cycle cost as a function of heating degree days and apartment size.

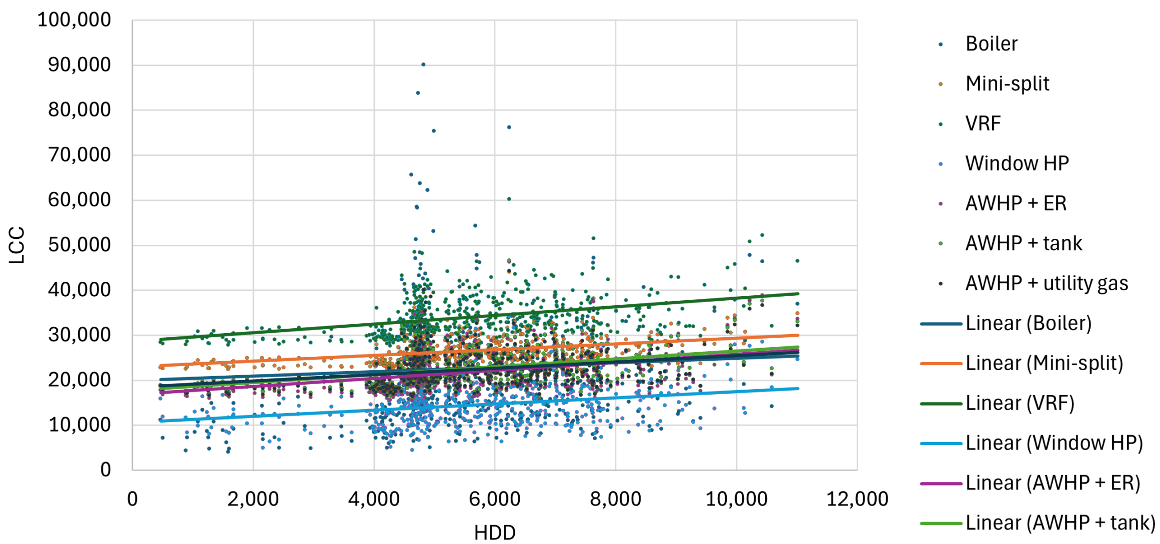

Figure B1. LCC (y-axis) as a function of heating degree days (HDD)

The R^2 values for figure B1 range from less than 0.1 (boiler, window HP, AWHP plus biomethane) to ~0.15 (mini-split, VRF, AWHP plus electric resistance, AWHP plus fuel tank) indicating that there is a weak-moderate relationship between LCC and heating degree days.

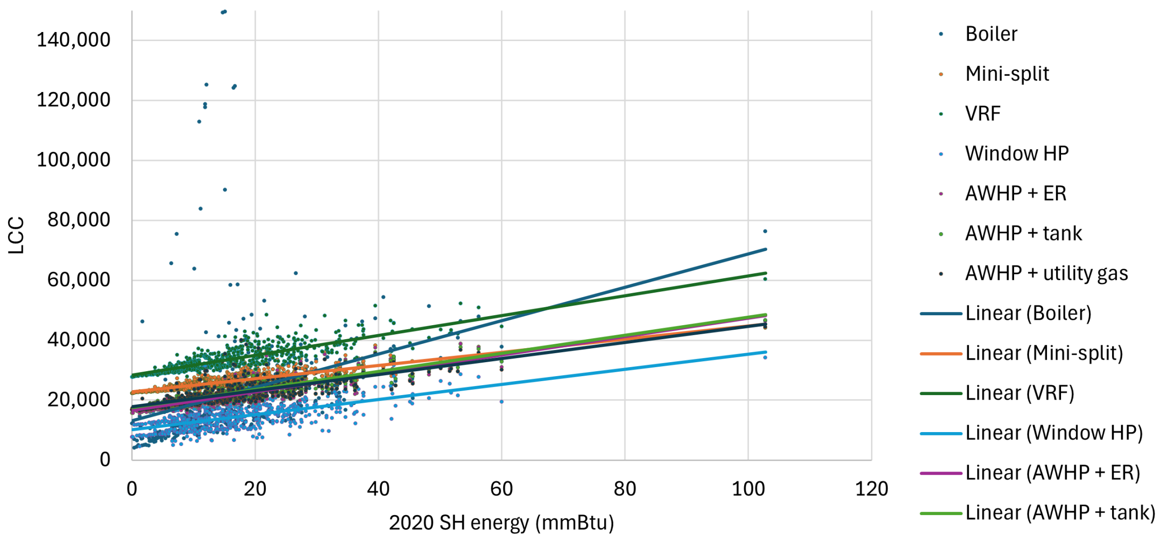

Figure B2. LCC (y-axis) as a function of basecase space heating energy use. Boilers using biomethane have the highest operating cost and hence the steepest slope.

There is a broad range in the strength of the relationship between LCC and space heating energy across the technologies, with R^2 values ranging from less than 0.1 (boiler) to ~0.75 (AWHP plus fuel tank).