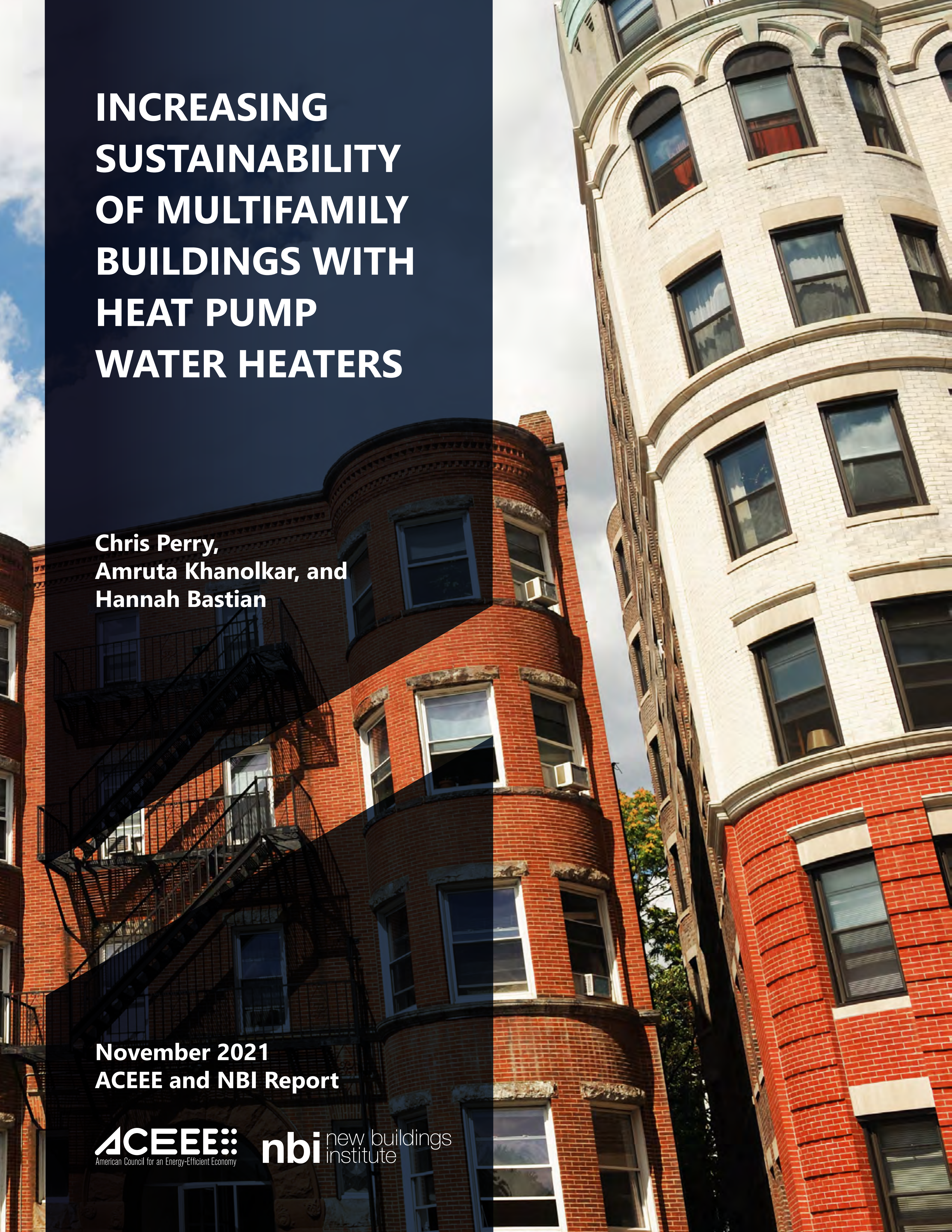

INCREASING SUSTAINABILITY OF MULTIFAMILY BUILDINGS WITH HEAT PUMP WATER HEATERS

Chris Perry,
Amruta Khanolkar, and
Hannah Bastian

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ACEEE and NBI Report

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nbi new buildings institute

Contents

About ACEEE and NBI

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.

New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in buildings. NBI works collaboratively with industry market players—governments, utilities, energy efficiency advocates and building professionals—to promote advanced design practices, innovative technologies, public policies and programs that improve energy efficiency and reduce carbon emissions. NBI also develops and offers guidance and tools to support the design and construction of energy efficient buildings. Learn more at newbuildings.org.

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Data Partners

Ecotope is a consulting, research, and mechanical engineering firm with 35 years' experience focusing on energy efficiency and sustainable design in buildings. Ecotope designs and implements central heat pump water heater systems, and its free Ecosizer Tool helps designers, engineers, and other stakeholders optimize the size and design of these systems. Ecotope's presentations and trainings are helping to educate the industry on central HPWH systems.

The Association for Energy Affordability (AEA) is a nonprofit provider of energy services, an implementer of government and utility energy efficiency programs, and a professional training organization serving the building performance industry and weatherization professionals. AEA specializes in both in-unit and central system heat pump water heater installations and provides critical technical assistance to utility programs such as the SMUD's Multifamily Program. AEA is currently leading an analysis on accelerating electrification in California's multifamily buildings.

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Executive Summary

KEY FINDINGS

- Our analysis shows that retrofitting natural gas water heating systems in existing multifamily buildings with heat pump water heaters (HPWHs) would result in energy savings of 85% and greenhouse gas emissions savings of 58%, while providing load-shifting benefits to the electric grid.
- However, the economics of retrofitting multifamily fossil fuel water heating systems with HPWHs are currently very challenging. A combination of policies and regulatory levers will be necessary to help make HPWHs more economically attractive for multifamily retrofit projects. Without significant interventions, multifamily HPWH installations will likely remain limited.
- The HPWH market is evolving quickly, and recent and soon-to-be-released products could help expedite the market transformation process and improve cost effectiveness.
- Estimated energy and emissions savings, as well as load-shifting grid benefits, are projected to be larger for central systems than for in-unit systems, but it varies by region.
- In cold climates and regions with unfavorable utility rates for electrification, a partial electrification approach (i.e., using heat pumps with natural gas backup) can be a short-term approach to reduce carbon emissions.
- Further research and design could help improve HPWH performance (e.g., in cold climates) and develop systems for specific applications (e.g., space-constrained low-income multifamily).
- Raising awareness and making training and technical assistance widely available is key to helping plumbers, installers, building operators, and building owners understand the unique considerations of HPWHs.
- Privately held properties with energy or carbon commitments and publicly and nonprofit-owned multifamily buildings may be good initial targets for HPWH retrofits.

BACKGROUND

From four-unit townhomes to large complexes, multifamily buildings use a significant amount of energy to provide hot water to their occupants. Much of that hot water is provided by natural gas and other fossil fuels, which emit harmful greenhouse gases (GHGs). Utilities and policymakers are increasingly looking to technologies such as electric heat pump water heaters (HPWHs) to help cut these emissions, while providing other benefits such as grid flexibility. However, relatively few case studies and limited data exist to help stakeholders understand the economics and potential benefits of having fossil fuel water heaters in multifamily buildings retrofit with HPWHs, as well as the types of program and policy interventions that could be used to transform the market. This study is a first attempt to fill those gaps.

MULTIFAMILY HEAT PUMP WATER HEATER SYSTEM TYPES

To heat water, multifamily buildings likely use one of two primary system types: an in-unit or a central system. In-unit water heaters are typically residential-style systems located in the dwelling unit (or in a mechanical closet outside the unit). Central systems are typically located in one or several mechanical rooms in the building, with each system serving multiple apartments. These systems heat and store hot water in a central location and typically use a recirculation loop to distribute the hot water throughout the building. Both system types can be retrofitted with HPWHs, but each type comes with its own unique considerations, such as allowing adequate space for airflow, accounting for increased noise, and ensuring sufficient electrical capacity.

EXISTING PROGRAMS AND POLICIES

Few efficiency programs currently target the multifamily sector specifically for HPWHs. California has the most attractive incentive programs, such as Sacramento Municipal Utility District (SMUD) and Bay Area Regional Energy Network (BayREN) programs. These programs offer between $800 and $2,000 per unit for an HPWH retrofit project, depending on the system type. Other program administrators, such as Bonneville Power Administration (BPA), Self-Generation Incentive Program (SGIP), and the New York State Energy Research and Development Authority (NYSERDA), are investigating ways to start new programs soon. Existing policies such as tax credits can help continue to incentivize HPWHs, and newer policies based around electrification and grid flexibility can further help boost HPWHs. Additionally, various national and regional market transformation programs, such as the Advanced Water Heating Initiative (AWHI),[1] are helping to create roadmaps, develop specifications, and accelerate HPWH market transformation.

ANALYSIS RESULTS

HPWHs save energy and reduce carbon emissions, while providing grid flexibility benefits (essentially acting as thermal energy storage tanks. Replacing natural gas water heating systems in multifamily retrofit applications with HPWH systems would save 175 trillion Btus per year of site energy and 6.5 million metric tons of GHG emissions[2] and provide 3.5

[1] A collaborative effort by New Buildings Institute along with key partners Bonneville Power Administration, Northwest Energy Efficiency Agency, ENERGY STAR®, Department of Energy, Pacific Northwest National Laboratory, Southern California Edison, Pacific Gas & Electric, California Energy Commission, California Public Utilities Commission, and Sacramento Municipal Utility District, and over 50 organizations, working to overcome HPWH market and technology barriers.

[2] Equivalent to one year of emissions from 1.4 million passenger vehicles (EPA 2021b).

terawatt hours of potential shifted energy to the grid. However, the economics of these retrofits are generally unattractive, with average payback periods of 20 years or more for in-unit retrofits and 30 years or more for central systems. Economics are the most challenging in cold climates and regions with low gas prices and/or high electricity costs, such as the Middle Atlantic. However, policy drivers such as efficiency program incentives, carbon pricing, and time of use (TOU) pricing can help make HPWHs economically viable in many applications.

RECOMMENDATIONS

Given that the economics are not yet attractive for widespread multifamily HPWH retrofits, supporting strong enabling policies, utility programs and rates, continuous research and development, and effective training will be key to successfully increasing the market penetration of HPWHs in the multifamily sector. Federal and state governments can encourage HPWH adoption using policies such as tax credits and bills that promote clean energy technologies. Other policies, such as carbon taxes and stringent building energy codes and equipment standards, can play a major role in supporting a shift to heat pump technologies.

Utility programs can also work to create comprehensive multifamily HPWH retrofit programs, which may incentivize not just the first cost of the unit, but also additional components (e.g., electrical wiring), and ongoing operational costs. In addition to efficiency and GHG reduction, a major benefit of HPWHs is their ability to essentially act as thermal batteries to shift load to off-peak hours. Although this capability is still in its infancy, especially for central systems, it is critical to start considering HPWH grid benefits now, as increasing electric loads (from electric vehicles and electric space and water heating), renewable energy generation (such solar and wind), and distributed energy resources (such as rooftop photovoltaics (PVs)) are rapidly changing grid characteristics and operation.

Manufacturers should also continue to build on their innovative HPWH technologies and bring new central system and in-unit designs to market. HPWHs that can operate successfully (and cost effectively) in applications for cold climates and space-constrained areas can help open the market for HPWHs. In markets that are particularly challenging, such as cold climates and those with high electricity costs and/or low natural gas costs, partial electrification approaches can be used in the interim to help reduce carbon emissions while maintaining cost effectiveness.

Finally, workforce education and training programs that can help people in trades such as plumbing and equipment installation learn about HPWH benefits and design strategies will be critical to ensuring the success of these technologies.

Introduction

Multifamily properties represent an important portion of the U.S. housing stock. In the United States, more than one-third of households rent rather than own, and the majority of those renters live in multifamily buildings (Clarion Partners 2018). These multifamily buildings typically share characteristics of the two primary types of U.S. buildings: low-rise residential buildings and commercial buildings. This means that technical considerations and program or policy approaches for the multifamily sector can also have important implications for the residential and commercial sectors.

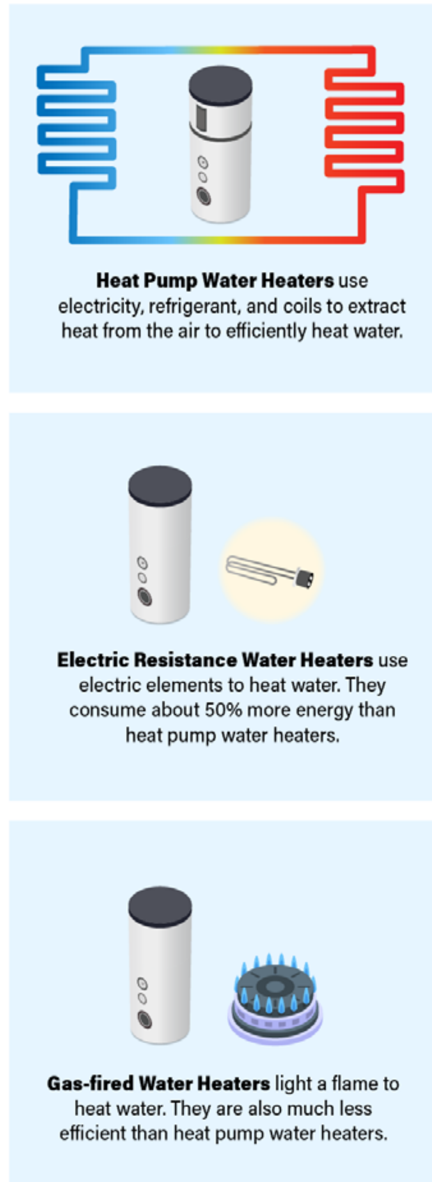

Figure 1. Water heater basics

As cities, states, and utilities increasingly pursue building decarbonization, ACEEE has witnessed a growing interest in understanding the barriers and opportunities for heat pump technologies. Heat pumps, which can be used for water heating or space heating and cooling, take advantage of the refrigeration cycle to transfer heat from one space to another (essentially like a refrigerator operating in reverse). Because heat pumps are typically all-electric, they have emerged as a way to help reduce dependency on fossil fuels. In its 2020 report *Electrifying Space Heating in Commercial Buildings: Opportunities and Challenges*, ACEEE found that retrofitting existing commercial buildings with space heating heat pump technologies could reduce energy consumption by 37% and greenhouse gas (GHG) emissions by 44% (Nadel and Perry 2020). In this study, we seek to provide utilities, policymakers, and other stakeholders with information about the barriers, benefits, and recommendations for retrofitting multifamily buildings with heat pump water heaters (HPWHs).

Our research shows that the majority of the transformative work in the multifamily HPWH space is happening in California, the Pacific Northwest, and New York. This study takes findings from these areas and attempts to extract broad lessons that apply nationwide. The sustainability benefits of HPWHs considered throughout this report include energy, carbon, economic, and grid impacts.

PRIOR STUDIES OF ELECTRIFICATION IN THE MULTIFAMILY SECTOR

While studies evaluating HPWHs in residential homes are relatively plentiful, analysis of HPWHs in multifamily buildings are relatively rare. This section highlights key multifamily

HPWH research that helped inform our study, including high-level heat pump and electrification studies, retrofit case studies, and heat pump installation guidelines. One of the earliest studies on HPWHs in multifamily buildings found that HPWHs were very economically attractive when compared to electric resistance water heaters, but that they struggled against natural gas water heaters due to the low cost of gas and the need for more efficient HPWHs. The researchers therefore suggested that "annual performance greater than a 2.5 COP[3] is needed for the HPWH to offer any operating cost advantage" (Hoeschele and Weitzel 2013). Figure 2 shows some of the key findings from that report.[4]

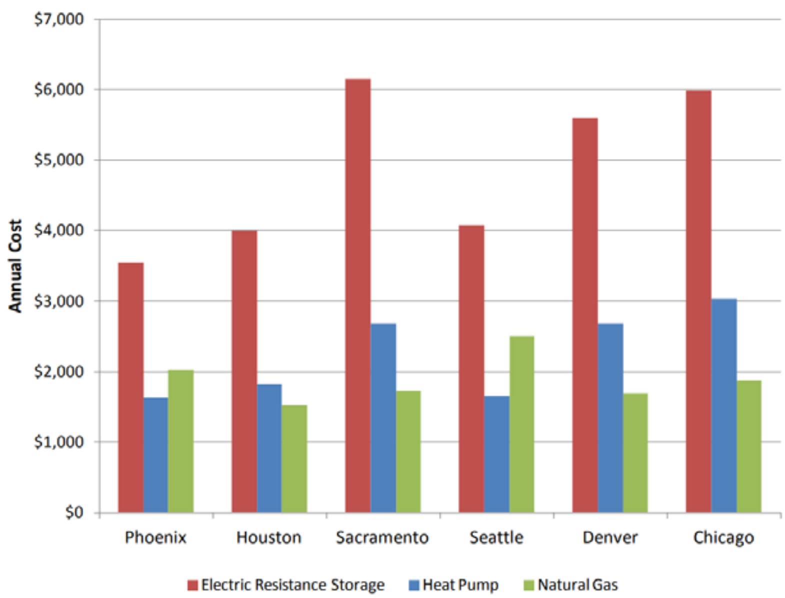

Figure 2. Cost effectiveness of heat pump water heaters in U.S. cities versus electric resistance and natural gas water heaters. Source: Hoeschele and Weitzel 2013.

More recent studies have evaluated different aspects of multifamily HPWH retrofits and electrification. In 2021, the Association for Energy Affordability (AEA) and Stopwaste released a report focusing on electrification of multifamily buildings in California and found a major gap in understanding of electrification technologies and design considerations, and that "whole-building electrification assessments" could play an important role in assisting in electrification education (Aitchison et al. 2021). Similarly, the Urban Green Council evaluated

[3] COP stands for "coefficient of performance," which is a simple way to measure efficiency, equivalent to the heat provided by the system divided by the energy consumed by the system. Due to thermodynamic limitations, it is not possible for electric resistance or natural gas systems to exceed a COP of 1, but the superior efficiency of heat pumps enables them to achieve COPs of 2, 3, or even greater.

[4] Heat pump water heaters now perform at much higher efficiency than 2.5 COP thanks to continued improvements from manufacturers.

the key challenges and needs to electrify multifamily buildings in New York City and found that strong planning and policy support will be required to electrify the city's fossil fuel space and water heating, which represents 40% of its emissions (UGC 2020).

Two well-documented case studies of multifamily HPWH retrofits help show the great potential for HPWH energy and carbon savings but emphasize the need for supportive policies, programs, and education. Bonneville Power Administration's report (conducted by Ecotope) on a CO_2 heat pump water retrofit in Seattle, Washington, documented high HPWH performance, while also noting several design issues and considerations (Banks, Grist, and Heller 2020). AEA's *Multifamily Clean Heating Pilot* report focuses more on electrification program development, describing findings from the Bay Area Multifamily Building Enhancements (BAMBE) incentive program. The report emphasizes the importance of providing attractive incentives, technical assistance, and contractor education (Dirr and Chitnis 2020).

Finally, two reports provide technical guidance for the installation of heat pump technologies. Eversource and Steven Winter Associates collaborated on a 2018 report providing guidelines for installing integrated HPWHs in multifamily buildings primarily for the Northeast United States, while in 2019, Steven Winter Associates released a broader report documenting heat pump retrofit strategies for multifamily buildings, covering both space and water heating (Eversource 2018; Steven Winter Associates 2019).

THIS STUDY

Due to the lack of analysis of water heat electrification in the multifamily sector and an increasing interest from policymakers, we conducted an initial national assessment of the potential for HPWHs to improve the sustainability of existing multifamily buildings, including reducing energy consumption and carbon emissions, while potentially providing grid flexibility benefits.

We posed the following research questions:

- What are the projected energy, carbon, and grid benefits of retrofitting existing multifamily fossil fuel systems with HPWHs?
- How do the economics change by climate zone or by adding utility incentives, carbon tax, or other measures?
- What are key challenges and design considerations for HPWH multifamily building retrofits?
- What additional considerations are needed for the affordable multifamily market?
- What research, programs, and policies help support the case for HPWHs in multifamily buildings?

To narrow the study's scope, we considered only retrofit scenarios in which the HPWH system was replacing a natural gas water heating system. Natural gas represents the largest fossil fuel water heating type, and when considering the economics of HPWH retrofits, replacing other fuel types—such as propane and fuel oil—will generally be more favorable than replacing natural gas.[5] Additionally, compared to replacing natural gas systems, it is usually much less challenging and more energy and cost effective to replace electric resistance water heating systems with heat pumps.[6] As the grid becomes cleaner, replacing natural gas water heaters with a high-efficiency electric HPWH also enables the largest GHG reduction benefits.

We did not consider new construction in this study. It is typically easier to design an all-electric building up front and save the cost of running a new gas line than it is to retrofit an existing building that is already connected to the natural gas network. Therefore, in attempting large-scale HPWH deployment, our greatest challenge will be retrofitting existing multifamily buildings with fossil fuel water heating systems. *NBI's The Building Electrification Technology Roadmap* dives deeper into the technology and industry status of a comprehensive set of decarbonization technologies that replace traditional combustion technologies, site barriers to adoption, and the road to accelerate adoption.

RECOMMENDATIONS

Table 1 summarizes our report's *recommendations* to help ensure proper installation and operation of multifamily heat pump systems, while also providing ideas to help accelerate the growth of the HPWH market.

Table 1. Summary of recommendations for HPWH multifamily retrofit installations

Category	Recommendation	Example(s)
System design and operation	Ensure that units are placed in the optimal operational setting	Place the unit in "heat pump mode"
	Design the heat pump system with grid flexibility in mind	Include an external or internal thermostatic mixing valve
	Consider including natural gas backup in areas with challenging economics	Consider "partially electrified" or "displacement" system approaches when a full HPWH system is not possible
	Pair with other energy- and water-saving technologies and measures	Tub spout diverter valve, drain-water heat recovery systems, and recirculation system optimization

[5] For example, Smarterhouse.org's water heater life-cycle cost table estimates that a conventional oil-fired storage water heater will cost a homeowner more than twice the cost of a conventional gas storage water heater over a 13-year life (Smarter House 2021).

[6] Two big reasons that this is true are that electric resistance and heat pump water heaters both use the same fuel (electricity) so they can be measured on an even playing field, whereas gas is relatively cheaper. Another reason is that the electrical capacity and wiring are likely to already be in place, reducing overall retrofit costs.

Category	Recommendation	Example(s)
Enabling programs and policies	Provide large incentives to achieve meaningful scale	Ideally $1,000+ per dwelling unit.
	Provide a variety of flexible program options	Include a package of multifamily measures and allow building owners to stage upgrades over time if desired
	Provide building owners with traditional and nontraditional technical assistance	Assistance can range from recommending technology design approaches to overcoming complex permitting requirements
	Consider incentivizing ancillary technologies	Incentives could include electrical upgrades such as panels, wiring, or transformers, or thermostatic mixing valves for grid flexibility
	Consider the most effective program approaches for the service area	Consider among upstream, midstream, or point-of-sale programs, and if plumbers and installers can receive some incentives, update rates to properly value grid benefits
	Improve building codes and equipment standards to incentivize HPWHs	Raise federal efficiency standards to HPWH levels, enact time-of-use pricing to incentivize grid connectivity, and include HPWH requirements in codes, require open standard connectivity
Future research and design	Investigate options for space-constrained applications	Seek more options for small wall-mounted units
	Design units to most easily enable grid flexibility	Include internal thermostatic mixing valves in units and standard connectivity ports
	Research the impact of ventilation from packaged in-unit systems on surrounding temperature and occupant comfort	Determine if it is acceptable to vent the system directly into the dwelling unit in some circumstances
	Develop more system types suited for cold climate applications	Design models with a defrost cycle and utilize refrigerants that maintain capacity in cold climates
Considerations for affordable housing	Consider options for retrofits with space- and power-constrained applications	New 120-volt HWPHs are one potential option
	Recognize that issues in market-rate multifamily buildings are often amplified in low-income multifamily buildings	Lack of capital to invest in upgrades, lack of on-site building staff expertise to operate and maintain equipment
Workforce and consumer education	Develop education and training programs to normalize early water heater replacement, fuel switching, and HPWH installations	Tools, specifications, standards, certifications for plumbers and technicians installing HPWH systems

Category	Recommendation	Example(s)
Subsectors to target first	Seek out multifamily property owners that will likely hold onto their property for a long period of time	Public- and nonprofit-owned multifamily buildings and multifamily buildings owned by private organizations with energy- or emissions-reduction commitments

Multifamily Water Heating Sector, Energy, and Emissions Trends

To gain a better understanding of water heating energy use in the multifamily sector, we used the most recent U.S. Energy Information Administration (EIA) Residential Energy Consumption Survey (RECS) data from 2015 (EIA 2018). Fossil fuel water heating represents the second largest end use in multifamily dwelling units, at an average of 22%. Figure 3 shows a breakdown of energy consumption across the multifamily buildings sector.

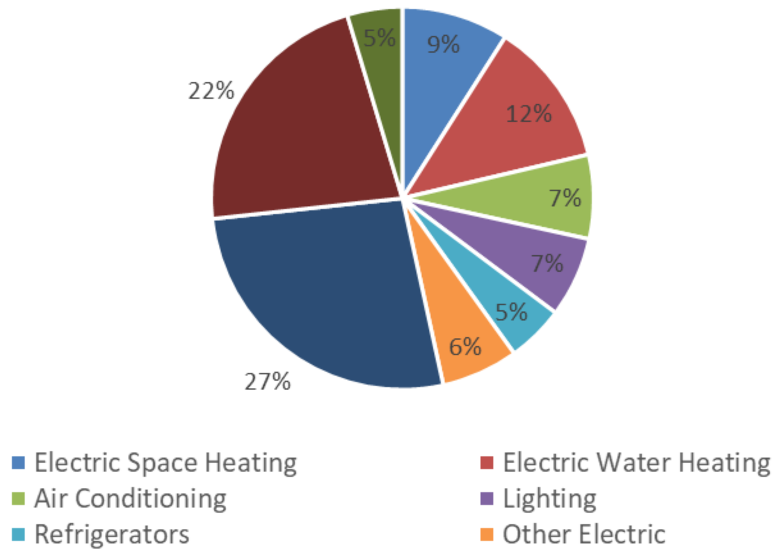

Figure 3. Shares of multifamily energy savings attributable to different end uses. Source: EIA 2018.

In multifamily buildings across the United States, fossil fuel (primarily natural gas) and electric water heating is split about evenly, as figure 4 shows.

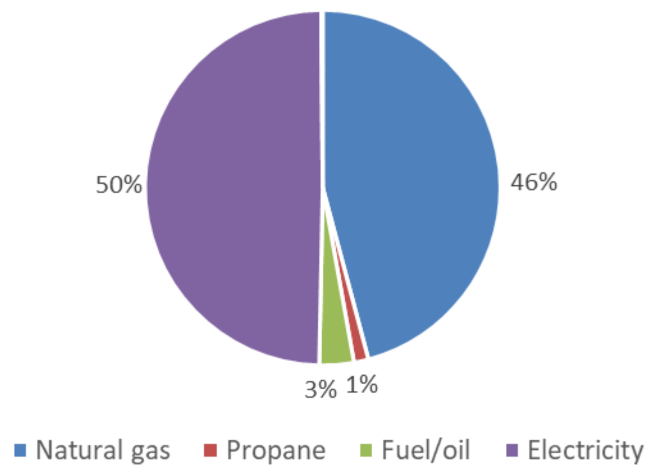

Figure 4. Multifamily building water heating fuel type. Source: EIA 2018.

However, there are large regional differences and general trends show that the majority of water heating in the Northeast, Mountain North, and Pacific is fossil fuel, while the South uses primarily electricity for water heating and the Midwest is fairly split between electricity and fossil fuel. Figure 5 shows a regional breakdown of energy consumption.

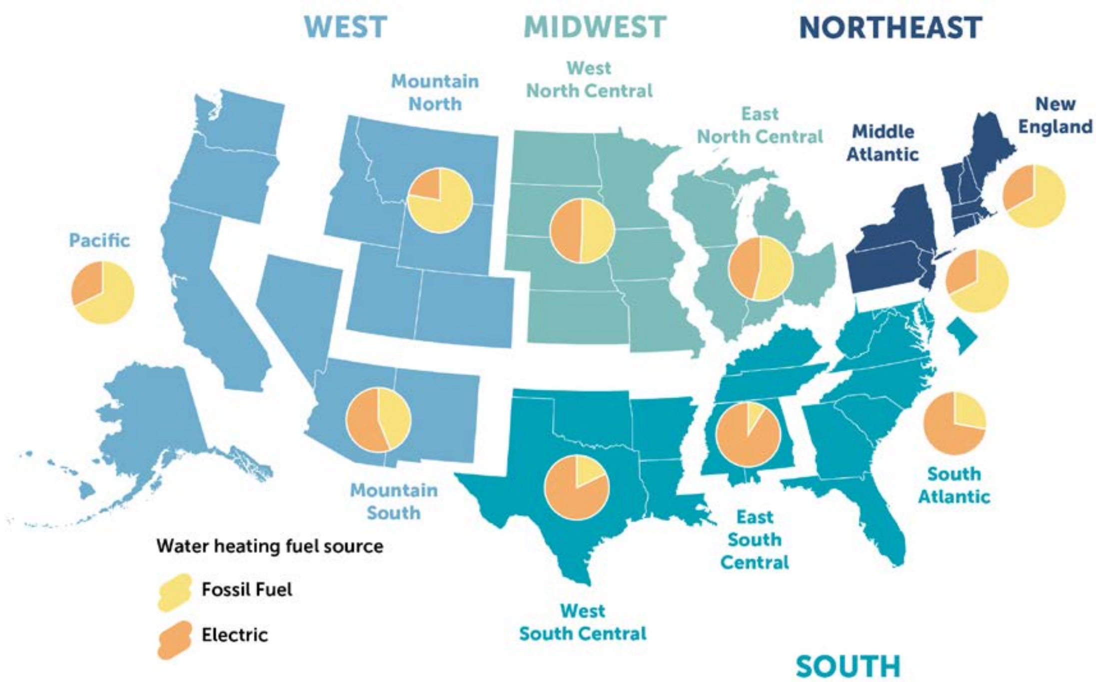

Figure 5. Water heating fuel source by region in the multifamily sector. Source: EIA 2018.

Looking exclusively at natural gas energy consumption, the Middle Atlantic, Pacific, and East North Central represent the largest gas users for water heating. New England and the South Atlantic fall somewhere in the middle, while the Mountain and remaining South regions represent significantly lower usage. Figure 6 shows natural gas water heating consumption by region.

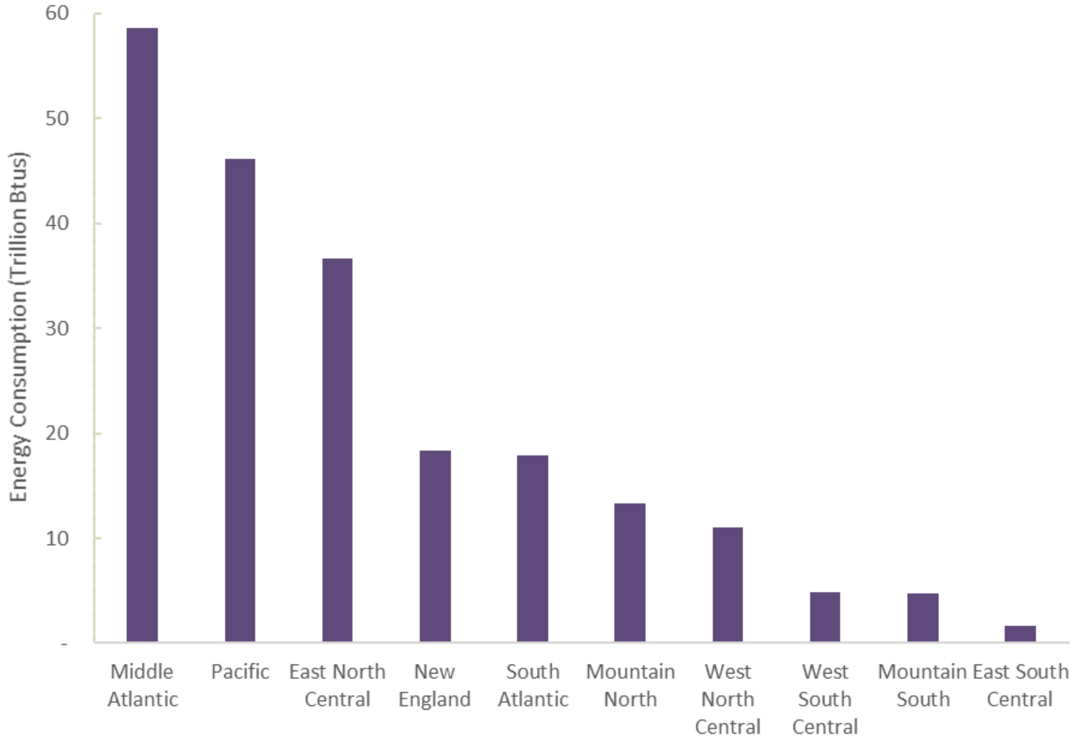

Figure 6. Multifamily building natural gas water heating consumption by region. Source: EIA 2018.

Data show that at a national level, slightly more water heaters are central systems (53%) than in-unit (47%). However, water heater system type varies greatly by region. The vast majority of water heaters in the South are single systems located within the dwelling unit, while systems in New England and the Middle Atlantic are predominately large central systems. Systems in the West and Midwest regions are more evenly split.[7] Figure 7 shows water heater types nationally and by region.

[7] The RECS database lists multifamily water heater location as either "in apartment" or "somewhere else in building." A conversation with the EIA's Chip Berry confirmed that these designations are intended to represent "in unit" and "central system" water heater types, respectively (C. Berry, RECS survey manager, Energy Information Administration, pers. comm., August 25, 2021).

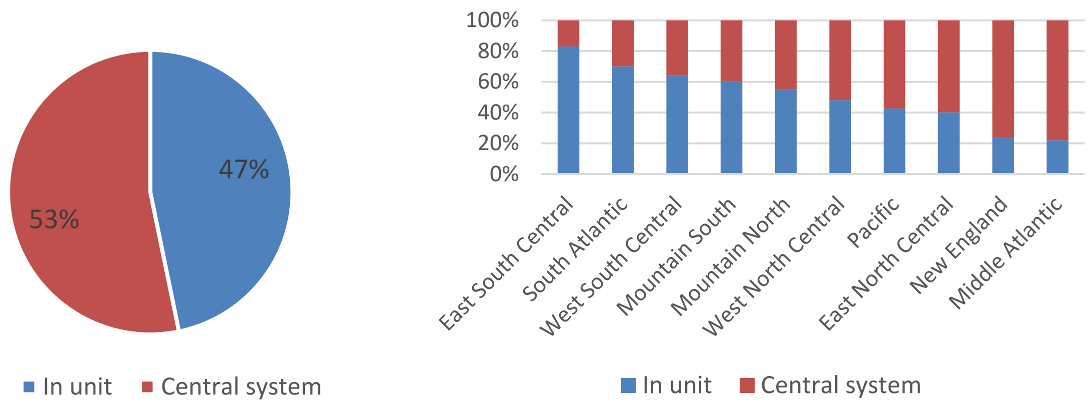

Figure 7. Water heater location nationally (left) and regionally (right). Source: EIA 2018.

Finally, to determine the relative number of each size of multifamily building, it is important to understand the distribution of the number of multifamily apartment units based on how many dwelling units were in those buildings. More than half of dwelling units are located in *large* multifamily buildings, which have more than 50 units, while 20% of apartments were in *small* buildings, which range from 2 to 4 units and include duplexes, triple deckers, and townhouse-style multifamily buildings. The remaining 24% are in *medium* buildings, which range from 5 to 49 dwelling units.[8] Although system types can vary by regions, most large buildings contain central water heating systems, most small buildings contain in-unit systems, and most medium buildings contain a mixture of both types. Figure 8 shows an approximate distribution of U.S. apartments by building size (i.e., number of dwelling units).

[8] We obtained these multifamily size categories from the paper, *Small and Medium Multifamily Housing Units: Affordability, Distribution, and Trends* (An et al. 2015).

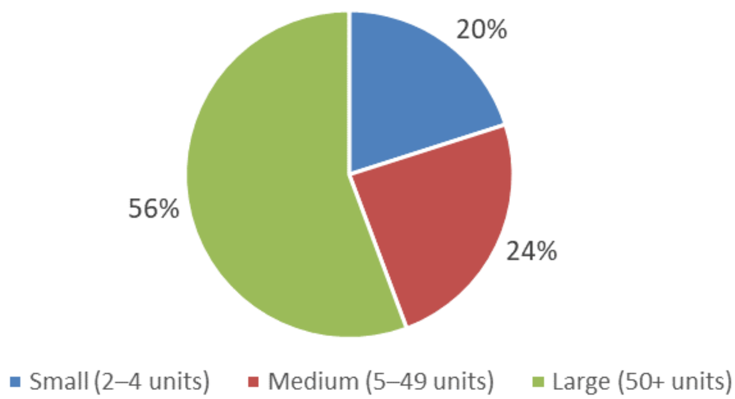

Figure 8. Approximate distribution of the number of U.S. multifamily dwelling units by number of dwelling units in the building. Sources: EIA 2018; Munger and Smith 2019.

Multifamily Heat Pump Water Heater System Types

Given the rapid changes underway in HPWH technologies and the evolving design guidelines, there is still much confusion in the industry about the different heat pump options for multifamily water heating. The easiest way to differentiate multifamily HPWH types is by the two primary categories: in-unit and central system. However, within these two categories are several subcategories of different system types. Each system type has its own unique design considerations for a multifamily retrofit project.

In most cases, an HPWH retrofit would replace an existing natural gas system with a similar style of HPWH system. For instance, if a building has a natural gas water heater in each dwelling unit, then it will most likely be retrofit with HPWHs in each dwelling unit. In most cases it would be impractical and cost prohibitive to convert to a central system, which requires complex additional piping. Similarly, a central natural gas system would almost always be replaced by one or more central HPWH systems.

Generally, smaller multifamily buildings tend to use in-unit water heaters, while larger buildings tend to use central systems. However, there is no universal size threshold that can accurately predict whether a given multifamily building will use in-unit water heaters or a central system (e.g., 40 units, four stories, etc.). This is because other factors—such as regional preference—play a large role. For instance, while the national split between the two system types in multifamily buildings is roughly 50–50, in the Pacific Northwest, less than 20% of multifamily buildings use central systems.[9] Conversely, multifamily buildings in New

[9] This trend appears to be shifting in favor of central systems for new construction.

York City rely almost exclusively[10] on central systems, which typically feed off central steam boilers located in the building's basement (M. Frankel, director of technology and innovation, Ecotope, pers. comm., May 6, 2021).[11]

IN-UNIT

In-unit systems may be located inside the apartment (typically in a mechanical closet) or outside the apartment (typically in either an exterior mechanical closet on a balcony or an interior HVAC closet near the apartment). In-unit systems may also be referred to as "per apartment" or "residential-style" systems.

System Types

Unitary

The most common type of in-unit HPWH available in the United States is a unitary system, which includes the tank and all internal heat pump components together in one singular package. These systems require a 240-volt connection and are typically found in single family homes. The four manufacturers with unitary systems available in the United States are A. O. Smith, Rheem, Bradford White, and Stiebel Eltron (see figure 9).

[10] Local Law 87 data show that in low-rise, high-rise, and very large multifamily buildings, water heating is approximately 95% or more completed by central systems. Central systems most commonly take the form of tankless coil or heat exchanger, which both absorb heat from the existing boiler heating system. However, they may also be direct-fired storage tank or a separate hot-water boiler and storage tank, both of which are central system types that are separate from the space heating boiler system (UGC 2020).

[11] Regional trends result from various factors. Primary reasons for New York City's high adoption of central systems include the high value of floor area in multifamily buildings, the relative ease and low cost of using existing steam heating systems for domestic hot-water systems, and the fact that the city has very large buildings, which would make maintaining hundreds of individual water heaters difficult. In contrast, the Pacific Northwest, which uses quite a bit of hydropower, has relatively cheaper electricity and a milder climate than New York, so design practice may have shifted to more in-unit electric and gas water heaters. The Pacific Northwest also has a greater prevalence of small- and medium-sized multifamily buildings.

Figure 9. The four unitary water heaters currently available in the United States are (from left to right) A. O. Smith Voltex Hybrid, Bradford White AeroTherm, Rheem Prestige Hybrid, and Stiebel Eltron Accelera. Source: Manufacturer product literature.

SPLIT SYSTEM

Split system water heaters separate the compressor from the tank. Although other models exist overseas, currently the only split system unit on the U.S. market is the SanCO_2 system, which uses CO_2 refrigerant and performs fairly well in cold temperatures. Due to higher up-front cost, these systems typically are not used for in-unit multifamily scenarios; they are much more commonly seen grouped together (in a central system style), as we describe in the Central System section. Figure 10 shows the SanCO_2 system.

Figure 10. Currently, one split system water heater is available in the United States: the ECO$_2$ Systems SanCO_2. Source: Manufacturer product literature.

120-VOLT

Multiple manufacturers are developing retrofit-ready, plug-in 120V HPWH technology, and one unit was introduced to market in spring 2021. This is an important advancement because the low-power 120-volt design can plug in to existing wall outlets without requiring expensive panel upgrades and/or home rewiring. This represents a good solution for retrofit applications to replace existing fossil fuel-fired tank type water heaters. The technology is expected to be well suited to smaller homes with lower hot-water demand, which are characteristics shared by many apartments. This emerging technology—if validated—has a tremendous GHG reduction potential compared to conventional gas-fired water heaters.

In addition to Rheem's dedicated circuit ProTerra Plug-In, which is currently available, at least five to six new products are coming to market within the next year from major manufacturers such as A. O. Smith, GE Appliances, and Nyle Water Heating Systems. All of these products meet the HPWH Advanced Water Heating Specification 8.0 (NEEA 2021) developed as part of the Advanced Water Heating Initiative (AWHI; see the Market Transformation Programs section of this report). The field assessment of this emerging technology will show the potential of this new class of water heaters as a plug-and-play solution to meet the retrofit market's needs. Figure 11 shows the emerging retrofit-ready HPWHs.

Figure 11. Emerging retrofit-ready 120V water heaters include (from left to right): Nyle (rendering), GE Geospring, A. O. Smith, and the Rheem Professional Prestige ProTerra Plugin. Source: Provided by manufacturers.

CENTRAL SYSTEM

Typically, larger multifamily buildings provide hot water to occupants through a central system, instead of through in-unit water heaters. These systems heat water in one or several locations and then pump it throughout the building via a recirculation loop.[12] The different configurations of central systems are more varied than in-unit products. Most retrofit examples to date use custom-built systems. However, manufacturers are in the process of bringing several new systems to the U.S. market, including prepackaged skid-mounted options.

Although different configurations of central systems exist, they often contain the same four main components: primary heat pumps, primary storage tanks, a temperature maintenance

[12] Small multifamily buildings may also use the traditional "trunk and branch" plumbing.

system,[13] and a mixing valve. Figure 12 shows these components and briefly describes their purpose.

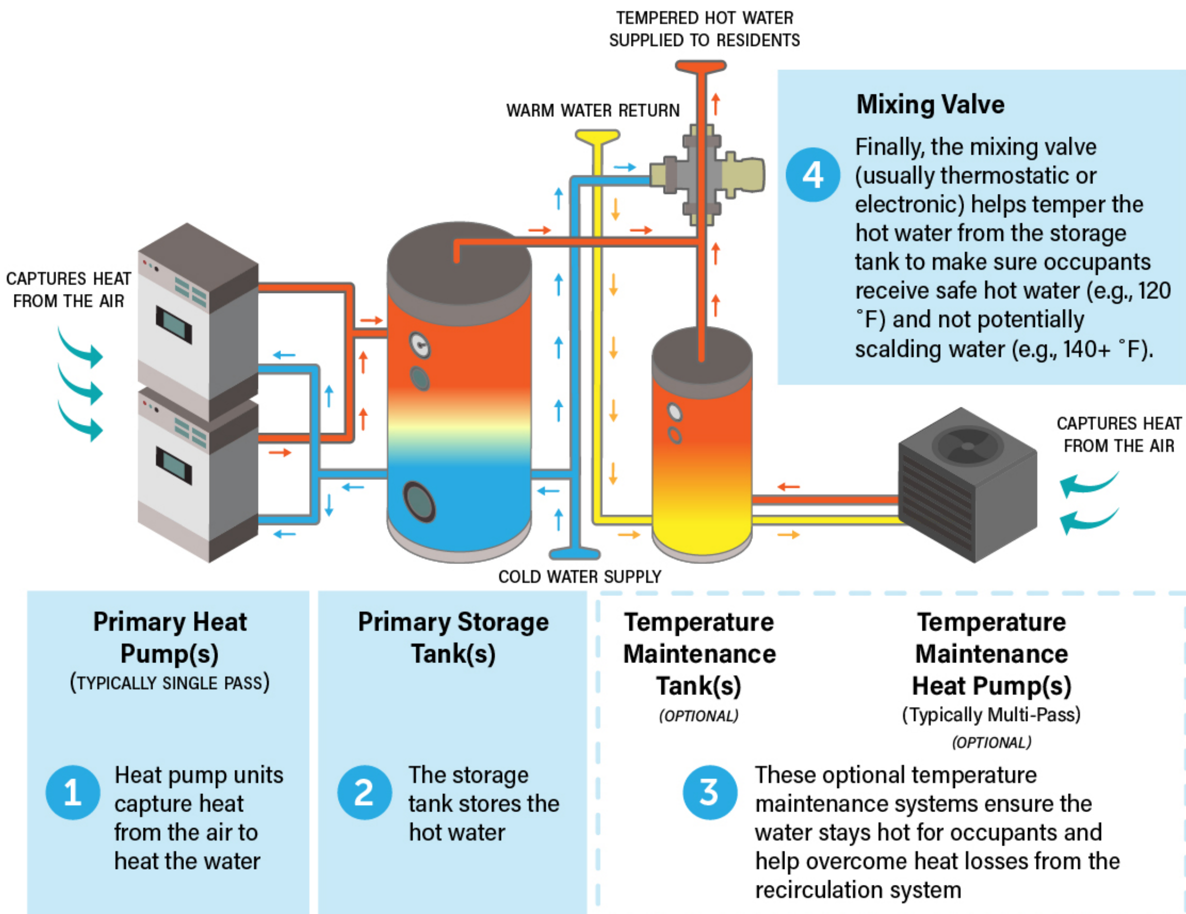

Figure 12. Primary components of central heat pump water heater system, showing a typical "parallel loop tank" configuration. Source: Created based on graphics and description from Kintner et al. 2020.

System Types

Large Central Split Systems

Central split HPWH systems are the most common system type used to replace central commercial natural gas boilers and water heating systems in multifamily buildings. Like in-unit split systems, central split systems separate the compressor from the tank. Each individual system typically has 10–30 tons of heating capacity (one "ton" is 12,000 Btus per

[13] Commercial HPWH systems do not always include a temperature maintenance system; sometimes, the primary HPWH handles both the primary and recirculation load.

hour). These systems are currently designed and custom built to suit each building's hot-water needs, which can result in a relatively high up-front cost. Manufacturers with large[14] central split heat pump systems available in the United States[15] include Mitsubishi, Nyle, Colmac, and AERMEC; figure 13 shows their units.

Figure 13. Large application central heat pump systems available in the United States include (from left to right): Mitsubishi QAHV/CAHV, Nyle C-Series, Colmac CxA Series, and AERMEC ANK Series. Source: Provided by manufacturers.

Ganged Residential-Style

Some installations *gang*—that is, connect—multiple residential-style HPWHs together to form a central system composed of smaller units. The system serves multiple units through a recirculation loop. An advantage of this system type is that if one unit breaks down, the system can still provide hot water. To get a rough understanding of size thresholds, Steven Winter Associates reports trying to limit its Sanden plants to a maximum of 20–25 units, which equates to approximately 60 dwelling units or fewer in the highly dense New York City market (though it likely equates to many more dwelling units in other parts of the country). For larger buildings over this threshold, it would typically make more economic sense to pursue a commercial-scale system. (N. Ceci, principal mechanical engineer, Steven Winter Associates, pers. comm., August 20, 2021). Figure 14 shows an example of a ganged system.

[14] These systems typically range from 10–30 tons each.

[15] Rheem will reportedly be bringing a large central system (currently available in Australia) to the U.S. market.

Figure 14. A ganged residential-style system that combines several $SanCO_2$ systems to create a central system. Source: Grist 2021.

A variation of this system type—sometimes referred to as "multi-central systems"—connects together multiple units to form a singular system, which then pipes hot water directly to the units rather than use a recirculation loop. Although currently uncommon, these systems are more cost effective than installing HPWHs in each unit and more energy efficient than central systems since they avoid recirculation loop heat losses (Gartman and Armstrong 2020). Another name for this system type is "semi-decentralized" (Brooks 2020).

Small Central Packaged Systems

For smaller multifamily buildings, small central packaged systems are another option. These systems are similar to residential packaged systems but are sized larger for commercial use. Although bigger than residential systems, they are much smaller than large central split systems; the units shown in figure 15, for example, are between 1 and 2.5 tons.

Figure 15. Small central packaged systems available in the United States include the Rheem Hybrid Electric Commercial (left) and the A. O. Smith CHP-120 (right). Source: Grist 2021.

Skid-Mounted Systems

Just becoming available in the United States, skid-mounted HPWH systems will contain all the main central system components—that is, a heat pump, storage tank, temperature maintenance system, and thermostatic mixing valve (TMV)—in one pre-assembled package. Unlike the current custom-built systems, these systems will be available essentially off-the-shelf, which can help reduce the up-front cost and the complexity of system design and installation. Multiple manufacturers are in the process of designing these system types. Figure 16 shows prototypes from Lync by Watts, Mitsubishi, and $SanCO_2$.

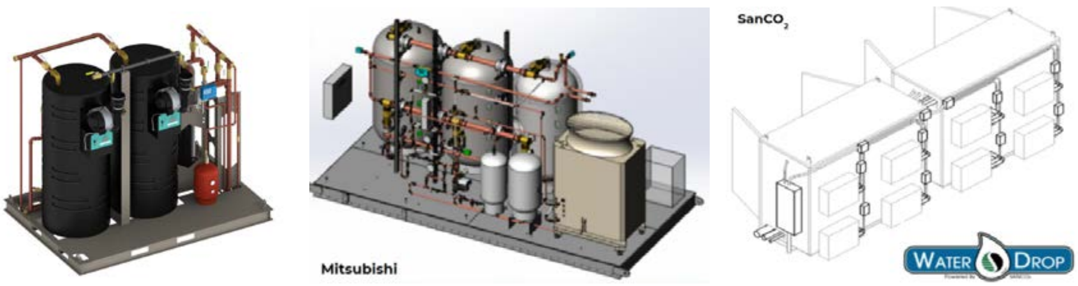

Figure 16. Example skid-mounted systems available or soon to be released in the United States: Lync by Watts, Mitsubishi, and SanCO$_2$. Source: Lync by Watts 2021; Grist 2021.

GRID FLEXIBILITY

In addition to exceptional energy efficiency, a primary benefit of HPWHs is that their tanks can act as thermal storage to provide grid benefits. Multifamily buildings are ideal for this due to the relatively high hot-water consumption and predictable water usage patterns. Both in-unit and central system HPWHs have the potential to provide benefits to the grid. However, this currently is more common in residential style in-unit HPWHs and has only begun to be introduced as an option for larger central systems.

The most promising contribution to grid flexibility from HPWHs is load shifting (sometimes called intraday balancing), in which electricity consumption is shifted from hours of peak demand to hours of low demand (Delforge and Vukovich 2018). In other words, the water heater draws energy to heat the water during times of excess energy supply, such as in the middle of the day when solar production is high. The HPWH then stops heating water during peak demand times, such as early evening, when solar production is low and multifamily residents come home from work and start using equipment and appliances.

For both in-unit and central system water heaters, the industry has moved to using the standard communications protocol CTA-2045[16] to facilitate communication between devices. This protocol relies on two components: a standard communications port installed by the manufacturer in the unit and a universal command module (UCM). The water heater, either in-unit or central, will be the *smart grid device* (SGD) and will decide the best response for the occupant and/or system operator. The UCM communicates to the SGD the requested response and the SGD responds with an acknowledgement of the request. Currently, UCMs support frequency modulation (FM), advanced metering infrastructure (AMI), powerline carrier, 4G, long-term evolution (LTE), and WiFi. The first version of the standard, CTA-2045-

[16] The standards and trade organization Consumer Technology Association (CTA) led the development of CTA-2045, which is now in the process of being rebranded to the more consumer-friendly name "EcoPort."

A, supported load shedding during peak times, while the latest version, CTA-2045-B (released in 2021), supports advanced functions such as advanced load up, time of use (TOU) scheduling, and sophisticated load shifting. Figure 17 shows an example of the CTA-2045UCM.

Figure 17. Example of CTA-2045 port and communications module. Source: Mayhorn, Ashley, and Metzger 2021.

A key water heater component that enables load shifting is a TMV. Load shifting works by heating the water to higher temperatures during off-peak times, which might mean at night in some regions or in the middle of the day in others (typically those with high renewable energy production). The water heater then can coast during times of peak demand. Since the water stored in the tank will be heated to higher temperatures that could potentially scald users, the TMV allows the high-temperature hot water to mix with cold water to provide tempered hot water to the occupants. Although TMVs are typically installed as a separate component, some manufacturers are starting to integrate them into their water heaters. All TMVs fail safe, so if a mechanical failure occurs, it results in cooler water not high tank temperature water. Figure 18 shows a diagram of a TMV and illustrates how the (super)hot- and cold-water inlets combine to provided (safe) hot water through the mixed outlet.

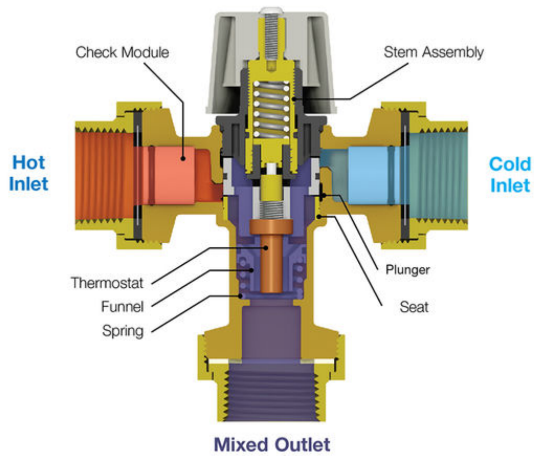

Figure 18. Diagram of a thermostatic mixing valve, a critical component for grid-connected HPWHs. Source: Watts 2021.

Although the mechanics of load shifting are similar for in-unit and central system HPWHs, utilities will likely interact with different systems in different ways. The power of in-unit HPWHs for load shifting is in numbers. Each individual unit by itself has relatively small load-shifting potential. However, a whole multifamily building of in-unit grid-connected HPWHs offers a much greater benefit to the grid. Third-party aggregators[17] have a history of managing fleets of distributed energy resources (DERs) such as grid-connected water heaters and are a likely candidate to help utilities manage in-unit HPWHs. In contrast, for larger central systems, the benefit does not come from aggregating many individual water heaters, but rather from taking advantage of the thermal storage of one or more large storage tanks. Once load shifting for these systems becomes more ubiquitous. it seems less likely that aggregators will manage the communication between these systems and more likely that the utility's DER management system (DERMS) will connect directly through the CTA-2045 module or to the building automation system (BAS) (if one exists).

[17] Aggregators act as intermediaries between utilities and customers to help customers manage their grid-connected devices and thereby help the utility better manage its load. Although the impact on the grid from one resource, such as an HPWH, is relatively small, the impact of many aggregated devices together can be quite large.

Multifamily Heat Pump Water Heater Policy and Program Overview

POLICIES

Policies can help drive the adoption of HPWH in multifamily properties in many ways. Well-designed policies can reduce the barriers to HPWH adoption, including by reducing costs, increasing awareness, and supporting workforce development. The sections below describe existing and emerging policies that can support HPWH adoption.

Tax Credits

Federal and state governments can offer consumer tax credits for HPWHs to reduce costs and make HPWHs more affordable and competitive with alternative water heating equipment. This is especially true in areas where tax credits can be combined with utility incentives. Currently, the federal government offers a $300 consumer tax credit for qualified ENERGY STAR® HPWHs (Energy Star 2021). This tax credit is set to expire at the end of 2021, but Congressional committees are working on proposals to extend and increase the incentive. For example, the Build Back Better Act passed in the house raises the HPWH tax credit to 30% of system cost with no maximum cap on the amount (Build Back Better Act 2021). State governments can also offer tax credits for HPWH. For example, in 2017, Oregon offered a $300 tax credit for HPWHs that met the Northern Climate Specification Tier 1 and $600 for HPWHs that met Tier 2 requirements (Oregon Department of Energy 2021).

In addition to consumer tax credits, the federal government can offer manufacturers tax credits for producing additional HPWH units. Such upstream tax credits act as an investment in heat pump technology and can bring consumer costs down through economies of scale (NRDC and ACEEE 2021). Manufacturer tax credits have many other benefits including domestic job creation, lower administrative costs, and greater potential to scale. They also can be more equitable than consumer tax credits because low-income families who own homes in multifamily buildings are unlikely to have the up-front capital to pay for heat pumps and cannot wait until filing taxes to receive the rebate. Owners of multifamily buildings may also face capital constraints; this is particularly true for affordable housing owners. ACEEE and the Natural Resources Defense Council (NRDC) have put forth a proposal to Congress for revising section 45M of the tax code to provide a manufacturer tax credit for heat pumps (NRDC and ACEEE 2021).

Federal Policies

Federal policies also present an opportunity to provide additional funding for energy-efficient multifamily retrofits and/or HPWH retrofits. For instance, the Zero Emissions Home Act (ZEHA) proposed by Senator Heinrich (D-NM) and several others provides incentives of $1,250 per multifamily unit up to 50% of the cost of high-efficiency equipment, including HPWHs. Low- and moderate-income and tribal households receive even greater incentives: $1,750 per dwelling unit and up to 80% of the cost of the equipment (Ungar, Nadel, and

Barrett 2021). As of fall 2021, this program may become part of the federal budget reconciliation bill.

BUILDING CODES

Although more important for new construction than for existing buildings, there are several ways that states and cities can drive adoption of HPWH through their building codes. Averting the worst impacts of climate change will likely require shifting overwhelmingly to HPWHs in new buildings, and yet current building code processes fail to adequately account for the costs of climate change and other externalities, thus often preventing this needed change. Expanding the codes scope to include additional values such as GHG emissions reductions or grid flexibility in code economic assessments could help make this possible.[18] The AWHI provides guidance for states and cities to begin collecting this data in its guidebook, *Bringing Heat Pump Water Heaters into the Mainstream* (AWHI 2021a).

There are more immediate changes that can be made that encourage HPWH installations. As in California, for example, codes can award compliance credits for HPWH installations (Delforge and Ashmoore 2020). Similarly, as in other parts of the country, codes can award points for HPWHs as part of additional flexible energy efficiency packages. Tangential to building codes, cities can also simplify and expedite the permitting process for electrical upgrades necessary for HPWH retrofits, ultimately reducing project times and costs.

ELECTRIFICATION POLICIES

States and cities across the country are adopting electrification policies to help meet their GHG emission reduction goals. Electrification policies call for shifting fossil fuel-dependent end uses, such as water heating, to electricity. These policies are relatively new, and many states still have fuel-switching policies that limit or prohibit policies and programs that encourage electrification. However, in setting aggressive GHG emission reduction goals, states have recognized the need to update policies and rules to allow for electrification. For example, in 2019, the California Public Utilities Commission revised its policy that prohibited utilities from providing incentives for measures that switched customers from gas to electric to now allow for electrification (Gerdes 2020).

Fuel-switching policies vary across the United States, as figure 19 shows.

[18] This may have helped an NRDC high-efficiency water heating proposal in the 2021 IECC that promoted products such as heat pump and grid-interactive water heaters. The proposal initially passed the committee but was later rejected for questionable reasons after an appeal process (Cheslak 2020).

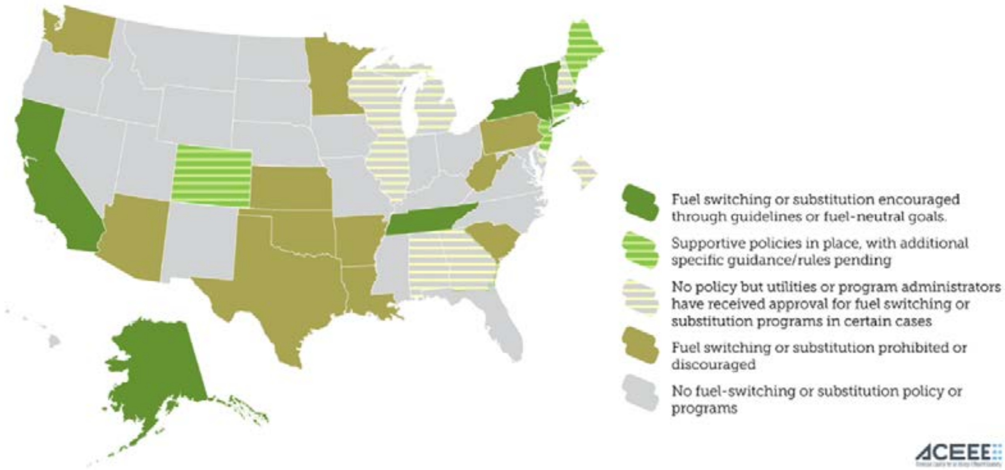

Figure 19. Fuel-switching policy status by state. Source: ACEEE 2020.

Cities are also adopting electrification policies. As of September 2021, 44 California cities have adopted building codes that encourage or require all-electric new residential construction (Gough 2021). For example, San Jose passed a natural gas ban for all new building types. While all-electric building codes primarily increase HPWH installations in new construction, these policies can also support installations in retrofits by raising awareness of these products amongst consumers and installers, thereby bringing the costs down through economies of scale.

Some cities and states are also pursuing building performance standards that set minimum energy and GHG performance requirements for large commercial and multifamily buildings. For example, New York's Local Law 97 sets GHG emissions limits for large buildings. Depending on how the requirements are set, these policies could encourage electrification of water heating in multifamily buildings.

Grid Flexibility and Modernization

States and utility regulators are putting forth plans for modernizing their grid-infrastructure and adopting policies to support these plans. Such plans include goals for decreasing GHG emissions, managing peaking loads, and increasing demand flexibility to meet intermittent supply from increased renewable generation. Grid-connected HPWHs are one promising technology for supporting all these goals.

A few states have included HPWHs in their grid modernization plans, policies, and programs. In 2020, the California Public Utilities Commission included $45 million for HPWHs in its Self Generation Incentive Program (SGIP). In addition, as part of California's SB1477, the state made approximately $200 million available for clean space and water heating technology adoption (the TECH and BUILD programs) to help ensure that clean heating technologies are accessible to all Californians. These funds will support programs that provide incentives for installing HPWHs, including multifamily-specific programs (Gerdes 2020).

Utility regulators can also support grid-connected HPWH adoption through approval of TOU rates. Allowing or requiring utilities to offer TOU rates can improve the economics of grid-connected HPWHs by compensating customers for shifting energy use during times with lower rates. Utilities and regulators can also support future grid-connectivity by requiring all incentivized HPWHs to have a CTA port and the ability to input TOU schedules.

ELECTRICITY PRICING

The price of electricity significantly impacts the cost to operate a HPWH and therefore has a significant effect on its overall cost effectiveness. For this reason, utility rate design will play a critical role in the adoption of HPWHs. Utility rates should ensure that customer choices and system value are aligned; that is, rates should motivate customers to decisions that reduce their own bills and reduce systems costs (LeBel 2020). As mentioned in the previous section, TOU rates can encourage customers to shift their energy consumption to low-cost times, thereby reducing their energy bills, improving the cost effectiveness of the HPWHs, and providing value to the grid through reduced demand during peak-load times (Shipley et al. 2018). In addition to rate design, pricing externalities such as carbon pricing and valuation in cost-effectiveness testing can also help make electricity-based technologies such as HPWHs more cost competitive with natural gas.

INCENTIVE PROGRAMS

Simplified and uniform incentive programs will be necessary complements to policies for driving HPWH adoption. Unfortunately, not enough programs are designed specifically for multifamily retrofits. However, many utilities offer incentives for general residential customers, including multifamily properties, offering downstream incentives for in-unit HPWHs ranging from $300 to $750 per unit.

While the general residential incentive programs are a great start, incentive programs designed for multifamily properties are necessary because of the unique challenges associated with multifamily buildings. Multifamily energy efficiency projects can be complex and have high up-front costs, and owners may lack the capital and time to pursue efficiency retrofits. Furthermore, owners may lack the incentive to invest in energy efficiency if tenants are responsible for paying the energy bill; in such cases, owners do not reap the financial benefits from energy cost savings.

We identified five multifamily programs that incentivize HPWHs in existing buildings. Sacramento Municipal Utility District (SMUD), Bay Area Regional Energy Network (BayREN), and Rocky Mountain Power (RMP) all offer incentives for both in-unit and central HPWH, while Baltimore Gas and Electric (BGE) and Orlando Utilities Commission (OUC) offer incentives for in-unit HPWHs only.

The SMUD and BayREN programs are similar in that they both emphasize electrification and energy efficiency. Their programs offer incentives based on the number of units in the building for both in-unit and central systems. BGE, OUC, and RMP offer custom incentives for numerous multifamily efficiency measures, including HPWH. Tables 2 and 3 summarize these programs and the incentive levels for in-unit and central systems, respectively.

Table 2. Incentive programs with in-unit heat pump water heater (HPWH) incentives for existing multifamily properties

Implementer	Program name	Incentive level
Sacramento Municipal Utility District (SMUD)*	Go Electric incentives for multifamily buildings	$1,500 per unit for apartment HPWH $1,500 per unit for common area HPWH (serves communal spaces)
Orlando Utilities Commission (OUC)	Multifamily Efficiency Program	100% of cost, up to $500 ENERGY STAR HPHW utilize super-efficient technology to cut water heating costs by more than half
Baltimore Gas and Electric (BGE)	Multifamily Tenant Equipment Program	Up to 50% of the cost of energy-efficient appliances for individual units in multifamily buildings, including hybrid HPWH
Bay Area Regional Energy Network (BayREN)	Bay Area Multifamily Building Enhancements Program (BAMBE)	$1,000 per unit for in-unit HPWH $1,000 per unit for laundry HPWH $1,000 per pool HPWH
City of San Jose*	Electrify San Jose Rebates	Up to cost for qualified HPWH and panel updates, maximum of $4,500 for all residents or $6,000 for income eligible residents
Rocky Mountain Power (RMP)	Multifamily Custom Program	$0.30 per kWh (market-rate rebate) $0.36 per kWh (low-income rebate)
New York State Energy Research and Development Authority (NYSERDA)*	Multifamily Performance Program–Enhanced Heat Pump Incentives	$900 per dwelling unit
Silicon Valley Clean Energy*	HPWH incentive	$2,000 for replacing natural gas water heater $1,000 for replacing electric resistance water heater
Puget Sound Energy	Multifamily retrofit incentives	$500 per unit

***These programs also offer incentives for panel upgrades.**

Table 3. Incentive programs with central heat pump water heater (HPWH) incentives for existing multifamily properties

Implementer	Program name	Incentive level
Sacramento Municipal Utility District (SMUD)*	Go Electric incentives for multifamily buildings	$1,000 per unit served for central HPWH with gas back-up $1,500 per unit served for central HPWH, 100% electric, <15-gallon heat pump storage per bedroom served $2,000 per unit served for central HPWH, 100% electric, >= 15-gallon heat pump storage per bedroom served
Bay Area Regional Energy Network (BayREN)	Bay Area Multifamily Building Enhancements Program (BAMBE)	$800 per unit served for central HPWH (2–18 units served) $100,000 total per property for central HPWH and $15,000 per property cap for mixed fuel central domestic hot-water systems
Rocky Mountain Power (RMP)	Multifamily Custom Program	$0.30 per kWh (market-rate rebate) $0.36 per kWh (low-income rebate)

***These programs also offer incentives for panel upgrades.**

Go Electric: A Modern Multifamily Electrification Program

The Sacramento Municipal Utility District (SMUD) Go Electric program offers some of the most robust HPWH incentives for multifamily buildings. The fact that the program is centered around building electrification gives it more flexibility to incentivize HPWHs. In the past, the multifamily program was modeled on a comprehensive energy efficiency approach that gave owners incentives for kWh savings. However, the new electrification program uses a deemed savings approach in which SMUD provides incentives for individual technologies that shift end uses to electricity. SMUD funds the program using electrification funds and supplements it with energy efficiency funds.

To participate in the program, customers submit an interest form to the program administrators. A multifamily program advisor (MPA) reviews the form and will reach out to the customer to begin scoping the potential project. This will include a virtual or in-person site visit to evaluate existing systems and potential upgrade opportunities. The MPA then works with the customer to submit an incentive reservation request that includes information on the project scope and construction schedule, a completed infrastructure capacity evaluation form, rent roll, and other information. Once SMUD approves the project, the customer can move forward with the installation of the approved measures. The program also requires participants to deliver a Tenant Engagement Plan that provides education to tenants about the project and about ways to save energy. After the project is complete, the MPA will verify that the project was completed and meets all the program requirements. Once the MPA signs off on the project, participants can submit an Incentive Payment Request to receive their incentives.

The Go Electric program provides significant up-front support to building owners interested in participating. Each interested building owner is assigned an MPA who can inform the owner about the available incentives and program requirements. Advisors help the building owners complete the application and grid impact report. They can also direct owners to additional program incentives, including incentives for transformer and panel upgrades that are identified in the grid impact report. Eligible low-income customers can also receive additional incentives. In addition to financial incentives, SMUD offers expedited and streamlined permitting, which can greatly reduce project time. Finally, the program allows building owners to make upgrades in a staged approach. For example, if owners can afford to install HPWH in only one-third of their units, they can still receive program incentives, and they can later return to the program to receive incentives for the remaining units. This is a particularly important design approach for multifamily building owners because they often do not have the up-front capital necessary to complete comprehensive retrofits all at once.

Grid Connectivity Pilots

Pacific Gas and Electric is slated to launch the WatterSaver Program for grid-connected water heaters in both single-family and multifamily homes in late 2021, but no other multifamily grid-connected HPWH programs currently exist. There are, however, many single-family and commercial building connected HPWH pilots that can serve as precursors to future multifamily programs. For example, the United Illuminated (UI) low-income Home Energy Solutions program offered a free Rheem HPWH if customers enrolled in the demand response program (St. John 2019). UI was able to successfully call on these water heaters during demand response events. Hawaiian Electric offers a commercial pilot, the Grid-Interactive Water Heater initiative (GIHW), that offers GIWHs to small and medium-sized businesses (St. John 2014). The pilot is testing several grid services including load shifting and grid regulation.

MARKET TRANSFORMATION PROGRAMS

A growing number of stakeholder groups are leading market transformation efforts to increase HPWH adoption across the United States. For instance, AWHI is a collaborative, market transformation effort by New Buildings Institute with key partners BPA, the Northwest Energy Efficiency Alliance (NEEA), and SMUD, and more than 145 other organizations, all working to overcome market and technology barriers to catalyze and transform the market toward higher HPWH adoption. While HPWHs have just 2% of market share among water heating technologies today (EPA 2021a), AWHI is laying the groundwork to increase the adoption rate steeply and rapidly and has working groups focused on residential and commercial technology and market advancement (AWHI 2021b). The multifamily sector is one area of focus for AWHI; as an example, it began research and development of cross-cutting training modules for central HPWH field testing of CO_2 HPWHs in large multifamily buildings.

In addition to AWHI, several other national and regional efforts are underway to help accelerate HPWH technology adoption. The ENERGY STAR water heater program meets with manufacturers regularly as part of the Manufacturers Action Council. Additionally, both NEEA and Building Decarbonization Coalition recently announced consumer HPWH campaigns.

Analysis Methodology for this Study

The following sections include analyses of emissions, economics, and grid impact when replacing existing fossil fuel water heating equipment at their time of failure with HPWHs in multifamily buildings. In this study, we relied on the multifamily building data from the RECS database to evaluate the energy use, emissions, economics, and grid flexibility potential for converting natural gas water heating systems to HPWH systems. RECS covers all residential building types for the entire United States and notes each building’s census region (see figure 20), allowing us to look at regional and national trends. In the following paragraphs, we briefly discuss our approach; additional details are in Appendix A.

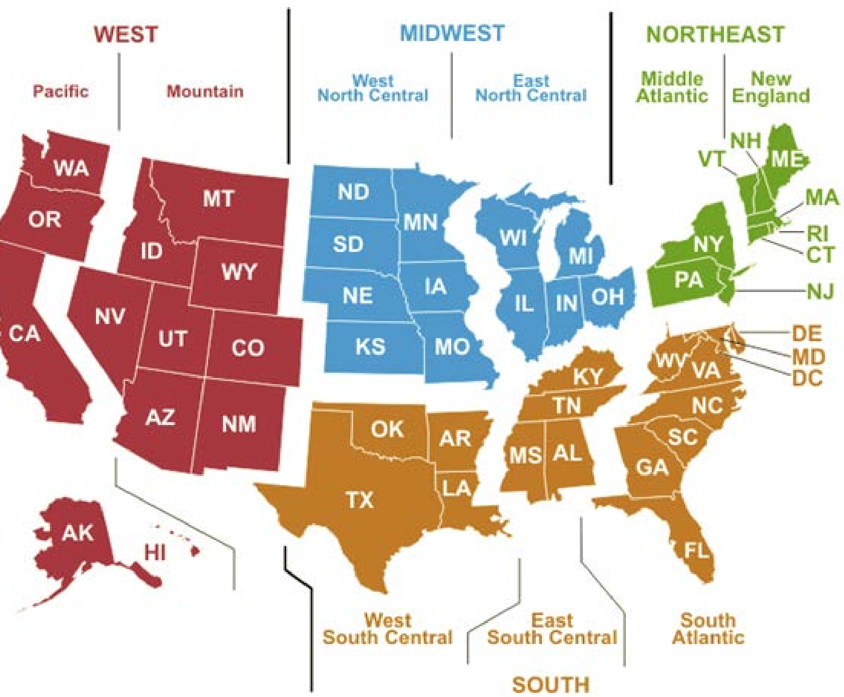

Figure 20. Census regions. Note that the Residential Energy Consumption Survey distinguishes "Mountain South" (AZ, NM, and NV) from "Mountain North" (CO, ID, MT, UT, and WY). Source: EIA 2021c.

Our analysis for water heating systems uses actual 2015 water heating energy consumption. We assumed existing natural gas systems met minimum federal energy efficiency requirements. We also assumed that HPWH performance varied by climate region; we then used this assumption to convert the natural gas water heating energy consumption to equivalent HPWH electricity consumption. Our HPWH efficiencies are based on studies that evaluated HPWH performance at different ambient air temperatures. For the water heater types that we evaluated in this report (average-sized residential and large-scale commercial), efficiency standards have not changed significantly in the past decade, and we assumed that the replacement natural gas system would be roughly equivalent to the one being replaced.

We then conducted an economic analysis from the building owner perspective, comparing up-front capital and operating costs of a high-efficiency HPWH system with a replacement fossil fuel system. Installed costs were obtained from publicly available data and studies, as well as from expert interview data. We developed high, low, and midpoint cost estimates for the installed cost of systems. We conducted our primary analysis (the medium-cost replacement) with the midpoint costs. We based energy costs on actual electricity and fuel costs paid by each building in 2015 as noted in RECS (which captures local and building-specific factors).[19] We then adjusted for energy price trends from 2015 to projected 2030 prices, per the EIA Annual Energy Outlook (AEO) reference case. We used 2030 because the new equipment will typically operate from 2020 until well into the 2030s. Using these capital and energy costs, we calculated the simple payback for each building, then averaged or calculated a median for each region and building type. Where possible, we present findings calculated using RECS weighting factors (which estimate the prevalence of the building type in the United States).

Our environmental analysis looks at the GHG emissions impacts of electrification in each building. For natural gas, we used the standard EIA emissions factor. For electricity, we assigned an emissions factor for each building based on average 2030 projected emissions per kWh in each region, per the EIA AEO reference case. We included a price on carbon emissions in a sensitivity analysis but not in the main analysis.

Limitations

This analysis is based on many assumptions, as described above and in Appendix A. These assumptions are generalized estimates and do not account for individual building situations. For example, equipment installation costs will vary from site to site. We also account for potential future changes in system efficiencies and costs in only a rudimentary way using our "low cost" scenario; as technology continues to advance and sales volumes increase with market penetration, we expect that equipment performance will continue to improve and costs will decline. Our analysis is also based on a single type of replacement system for each system type when, in fact, multiple options are available. For some buildings, a different system type might be a better choice than the systems we modeled. Furthermore, our analysis is mostly based on average cost per kWh of electricity and only very generally attempts to account for the specific impacts of TOU and seasonal rates and demand charges. As a result, our analysis should be considered approximate and not a substitute for analyses on individual buildings that can and should be conducted when making equipment replacement decisions.

One major limitation of this study comes from the constraints of the RECS database for central water heating systems. First, the RECS database provides information from a dwelling unit perspective and not from a whole building perspective, which is more challenging when evaluating a central system.[20] Next, the RECS database does not provide sufficient information on multifamily building sizes, only distinguishing between whether the building

[19] Electricity costs are static and do not consider TOU variation. The load-shifting scenario attempts to capture the effects of TOU rates.

[20] RECS also does not provide an estimated number of dwelling units per building for any multifamily building with more than four apartments.

has 2–4 units or five or more units. The differences between a 10-unit multifamily property and a 300-unit property are significant, yet we cannot distinguish between these using the RECS database, removing an opportunity to evaluate energy, emissions, economics, and grid benefits by building size.

Likewise, our sensitivity analyses on carbon pricing and utility incentives use a single set of assumptions. Many other options are possible that we have not analyzed.

Another limitation is the low sample size in certain census divisions, possibly due to those system types being less prevalent in those areas. Although the sample size was sufficient for most divisions (e.g., RECS has 63 examples of multifamily buildings with in-unit natural gas water heaters in the Pacific region), other regions were much lower. For the in-unit analysis, this includes East South Central (4 examples), New England (5), and Mountain South (9). For the central system analysis, this includes East South Central (one) and West South Central (eight). We considered dividing the analysis into the four major regions (West, Midwest, Northeast, and South), but this does not capture the varied climates in each region. Appendix B provides additional analysis by the four main regions (Northeast, South, Midwest, and West) and climate types (Marine, Hot-Dry/Mixed-Dry, Cold/Very Cold, Hot-Humid, and Mixed-Humid); however, this does not capture regional differences in the price of electricity and natural gas. While the census division analysis is the most useful, it has a higher uncertainty than the aggregated results due to the small sample size in some of the divisions.

Our analysis is based on fully converting buildings to electricity. As we discuss later, supplying some or most hot water with heat pumps and the remainder with a natural gas backup may make sense in some or even many applications. We did not include this option in our analysis because the supplementary heating from natural gas is sensitive to the local heating degree days and microclimate, which would have exponentially increased the complexity of the analysis.

This analysis uses the present natural gas system as the base case. Given the need to decarbonize large portions of the U.S. economy to meet climate change goals, the alternative case in future years should perhaps instead be a gas-fired HPWH fueled with renewable fuels such as green hydrogen or renewable natural gas such as biogas. This alternative case would be substantially more expensive than the present system and would still emit GHG emissions when burned. We did not examine this alternative to keep our scope manageable—and because the costs of this alternative system are highly uncertain.

Finally, our analysis is based only on existing buildings. An analysis on new commercial buildings would be very useful because, as discussed above, residential-sector analyses show better economics in new construction than in existing buildings.

Analysis by System Type

In this section, we outline the results of our analysis of replacing existing natural gas water heating systems with in-unit or central HPWH systems. We also offer a detailed building-by-building analysis for both in-unit and central system HPWH types, with aggregated results.

IN-UNIT

This section details results for installing in-unit HPWHs in all existing multifamily buildings that use in-unit natural gas water heaters. The analysis can help illuminate the relative energy, emissions, cost, and grid implications in different regions throughout the country. However, using current installation guidelines, this may be unrealistic in some settings due to ventilation requirements, space constraints, and electrical restrictions detailed in the Multifamily Heat Pump Water Heater System Types section and in Appendix C (Design Considerations). In total, the RECS database contains detailed data on 192 examples of dwelling units with in-unit water heaters, representing 4.5 billion square feet of multifamily floor space. The analysis compares the installation of a new natural gas tank water heater that has a uniform energy factor (UEF) of 0.63 with an HPWH that has a UEF ranging from 2.7 to 3.5, depending on the climate.[21]

Energy Savings

In all regions, in-unit HPWHs reduce site energy use. Although in-unit HPWHs vary in performance based on several factors, their energy efficiency rating (UEF) is typically four to six times higher (i.e., more efficient) than a standard gas tank water heater.

Due to its high number of in-unit natural gas water heaters,[22] the Pacific region has the greatest potential for energy savings—nearly twice as high as the next highest region. It is followed by the Middle Atlantic, East North Central, and Mountain North. Figure 21 shows the results.

[21] Uniform energy factor (UEF) is the metric that represents a residential-style water heater's efficiency. The higher the UEF, the more hot water it produces per energy used to heat the water.

[22] California's high saturation of gas water heaters, which represent about 90% of its residential water heating (Hopkins et al. 2018), likely skews the Pacific data to be much higher in natural gas water heating, whereas Washington and Oregon represent closer to a 50/50 split between electricity and gas (G. Wickes, senior product manager, Emerging Technologies, Northwest Energy Efficiency Alliance, pers. comm., August 18, 2021).

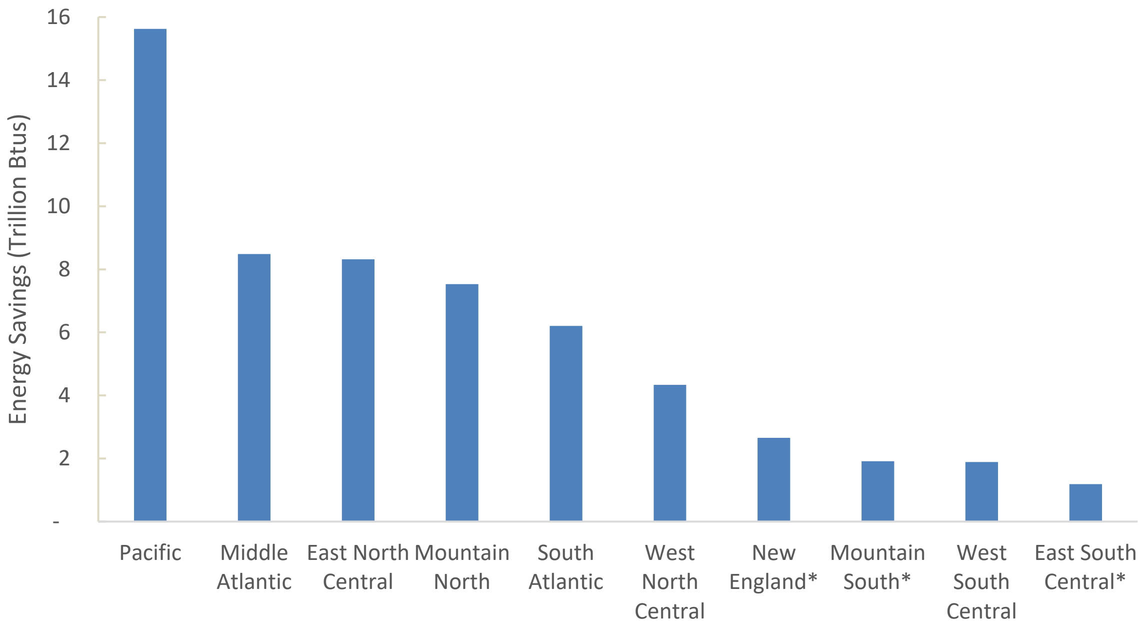

Figure 21. Total energy savings by region from installing an in-unit heat pump water heater (HPWH) where an existing natural gas water heater needs to be replaced. *indicates low sample size (n<10)

EMISSIONS

Results show that electrification of in-unit multifamily water heating can reduce GHG emissions in all parts of the country. As with energy savings, emissions savings were by far the highest in the Pacific region due primarily to its large number of in-unit natural gas water heaters, but also due in part to its clean grid mix relative to other parts of the country. Following this region are the Middle Atlantic, Mountain North, East North Central, South Atlantic, and New England regions. These emissions reductions are based on average regional emissions in 2030 as estimated by EIA (2020a).[23] Figure 22 shows emissions data for in-unit retrofits.

[23] While average emissions savings can provide a starting point for estimating emissions reductions, it does not capture the time value of emissions savings. For instance, HPWHs will increasingly operate in the middle of the day when solar photovoltaic energy is most abundant, thus greatly reducing emissions during these hours. New tools, such as the National Renewable Energy Laboratory's Cambium tool, can better capture the time value of HPWH emissions savings in future studies (NREL 2021).

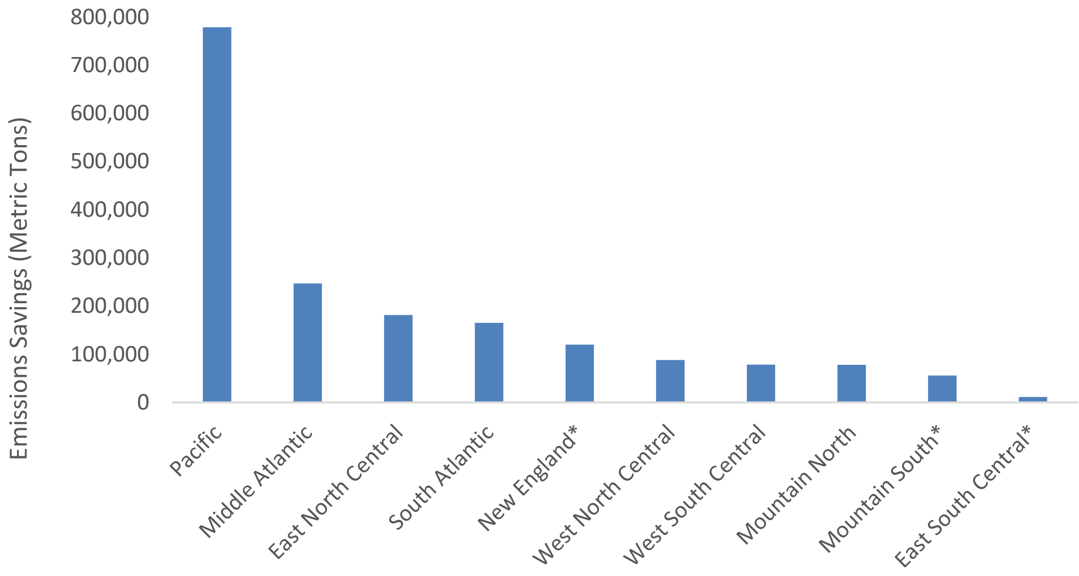

Figure 22. Estimated net emissions reduction by region from installing an in-unit heat pump water heater (HPWH) where an existing natural gas water heater needs to be replaced. *indicates low sample size (n<10)

ECONOMICS

In-unit HPWHs perform better in warmer and milder climates. The average simple payback is 20–35 years when replacing gas water heaters. In three climates—the Middle Atlantic, New England, and West North Central—HPWHs did not pay back at all (i.e., on average they did not save energy costs compared to a natural gas replacement) due to lower performance in cold climates combined with significantly higher average electricity rates (in the Middle Atlantic and New England) and lower natural gas rates (in East North Central). Figure 23 shows the average simple payback by region.

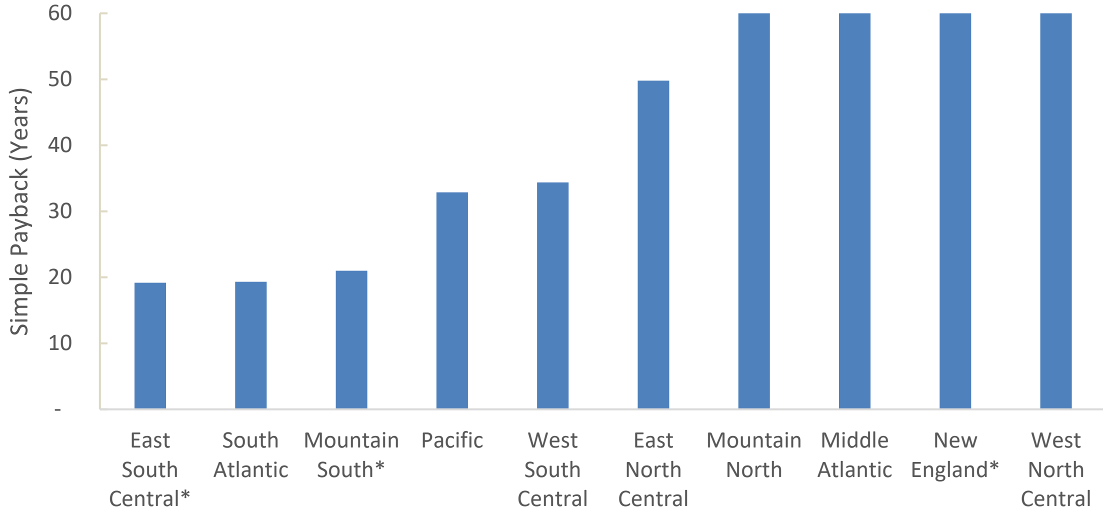

Figure 23. Average simple payback by region from installing an in-unit heat pump water heater (HPWH) where an existing natural gas water heater needs to be replaced. This figure does not include the impact of incentives, load shifting, or carbon pricing. *indicates low sample size (n<10)

Policy Scenarios and Sensitivity Analysis

Electrification economics are sensitive to costs and ongoing savings, so evaluating different cost and policy scenarios is important. In addition to our base medium installed cost, our analysis included three policy scenarios.[24] Given that these scenarios are largely hypothetical for most parts of the country, we include detailed information about our assumptions in Appendix A. The three scenarios were as follows:

- A utility incentive scenario in which a program provides an incentive of $800 per HPWH, which is an approximate midpoint of the incentives offered by the multifamily HPWH programs identified in this report.
- A carbon-pricing scenario in which a $50/ton fee is levied on carbon dioxide emissions, both on natural gas used in gas heating systems and fossil fuels used to generate electricity.
- A load-shifting scenario in which the water heater is capable of shifting 78 kWh per year and earns $0.20/kWh for shifted load, resulting in $15.60 earnings per water heater per year.

Figure 24 shows the results of these scenarios. In the best-performing regions in the southern United States—East South Central, South Atlantic, and Mountain South—incentives

[24] An additional sensitivity scenario not evaluated here is the impact of combining solar photovoltaics with HPWHs; several experts interviewed for this study indicated that such a scenario is a viable option to help improve economics.

had a substantial impact. A combination of all three incentive scenarios reduced the medium cost simple payback from more than 20 years to less than 10 years. Similarly, in the Pacific region, the combination of incentive scenarios reduced a 33-year simple payback to 10 years. However, even in the combined policy scenarios, the regions with the most challenging combinations of climate and utility rates still struggle with long payback: 17 years in New England, 21 years in the Middle Atlantic, and 29 years in the West North Central.

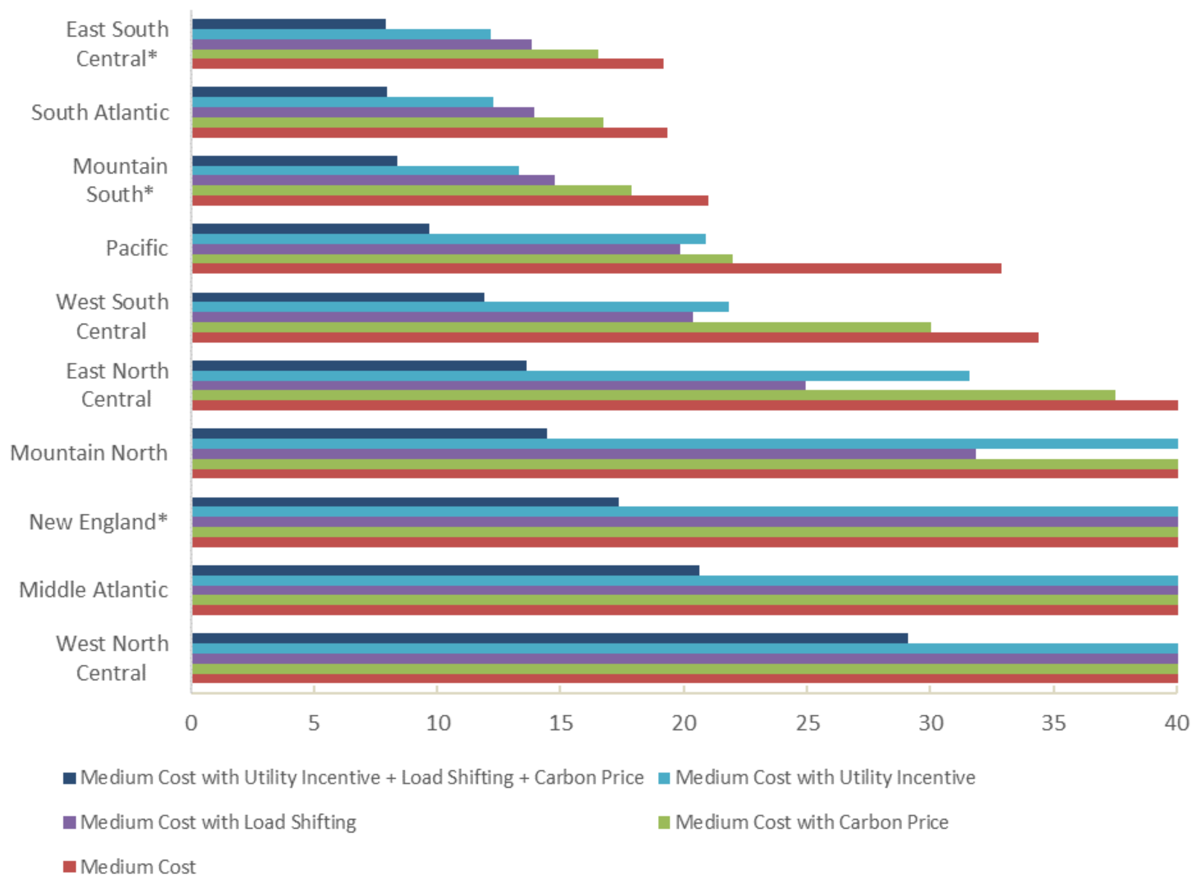

Figure 24. The impact of different policy scenarios on each region's average simple payback from installing an in-unit heat pump water heater (HPWH) where an existing natural gas water heater needs to be replaced. *indicates low sample size (n<10).

Replacing Electric Resistance Water Heaters with Heat Pump Water Heaters

Although the focus of this study is on replacing fossil fuel water heating systems, replacing electric resistance water heaters represents a major (and typically more economically attractive) opportunity. Using a similar modeling approach, we determined that replacing in-unit electric resistance water heaters with HPWHs would save 14.6 billion kWh (50 million kBtu) and 500,000 metric tons of GHG emissions. The average homeowner saved nearly $200 on their water heating bill, and the average simple payback ranged from 2.9 to 5.4 years without the help of incentives. Due to the large number of existing electric resistance water heaters, the South (South Atlantic, East South Central, and West South Central) represented the largest opportunity, with 9.5 billion kWh savings and 360,000 metric tons of emissions savings. However, East North Central also represented a significant opportunity (1.3 billion kWh savings and 60,000 metric tons of GHG savings), as did the Pacific region (1.4 billion kWh savings and 18,000 metric tons of GHG savings).

Our study also evaluated the relative impact of increasing or decreasing different variables used in the analysis by 25%. Results show that the cost of natural gas has the greatest overall impact, followed by the efficiency of the heat pump and the cost of electricity. Although policy scenarios, such as utility incentive and carbon price, are less sensitive than other variables, they also have a greater ability to reduce first cost by simply existing. Figure 25 shows the results from our sensitivity analysis.

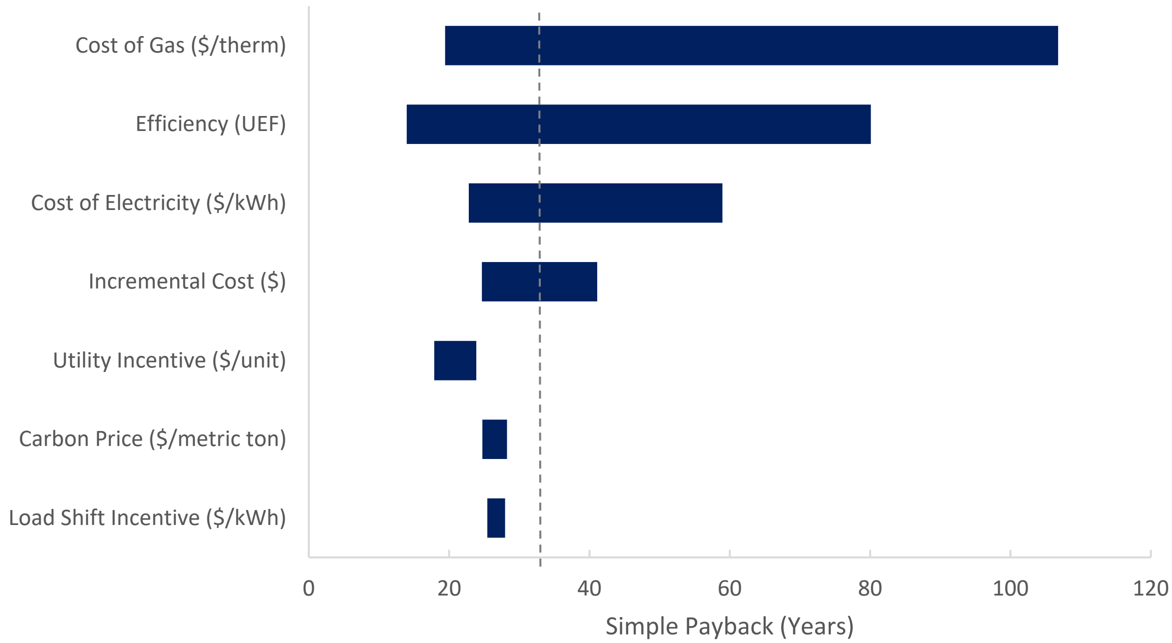

Figure 25. Sensitivity analysis illustrating the relative impact of different variables from installing an in-unit heat pump water heater (HPWH) where an existing natural gas water heater needs to be replaced. This sensitivity analysis is based in the Pacific region only, since some of the sensitivity cases in other climates resulted in some variables never paying back (which cannot be depicted graphically). The gray dotted line represents the average simple payback for an in-unit HPWH multifamily retrofit in the Pacific region (with no incentives) at 32.9 years.

Grid Flexibility

A primary benefit of grid-interactive HPWHs is their ability to "charge up" during different parts of the day so they can avoid using energy during peak grid times. This can help utilities better manage dramatic changes to load shapes as solar photovoltaics, electric vehicles, and other electric technologies continue to join the electric grid. It can also benefit multifamily building occupants or owners by helping reduce energy bills. Figure 26 shows the regions with the highest potential to obtain load-shifting benefits from grid-connected in-unit HPWHs, with the highest being the Pacific, followed by East North Central, Middle Atlantic, and South Atlantic.

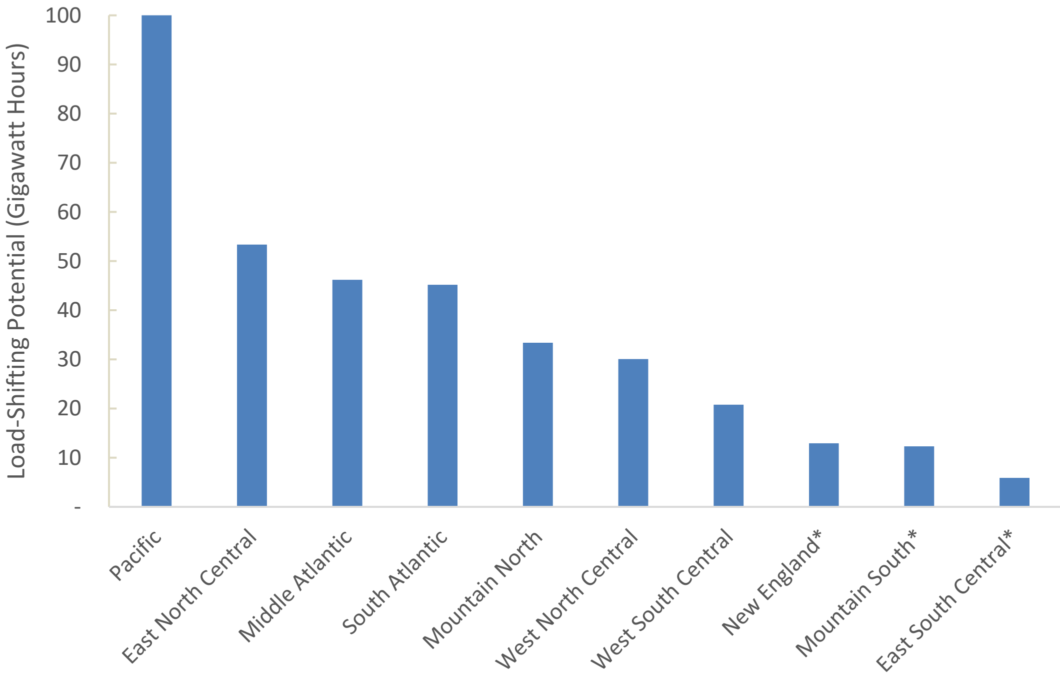

Figure 26. Total load-shifting potential by region from installing an in-unit heat pump water heater (HPWH) where an existing natural gas water heater needs to be replaced. *indicates low sample size (n<10)

CENTRAL SYSTEM

This section details the results for installing central HPWHs in all existing multifamily buildings that use central system natural gas water heaters or (water heating) boilers. The RECS database contains detailed data on 357 examples of dwelling units with central water heaters, representing 8 billion square feet of space. The analysis compares the installation of a new natural gas tank water heater with a coefficient of performance (COP) of 0.59 to a HPWH system with a primary heat pump system and heat pump/electric resistance temperature maintenance system with total system efficiencies ranging from 3.42 to 3.74, depending on climate.

ENERGY SAVINGS

Central HPWH systems save site energy in all regions and have the potential to save the most energy in the Middle Atlantic region, due primarily to its high number of multifamily buildings with central natural gas systems. The Pacific, East North Central, and New England regions also show relatively high potential energy savings. Figure 27 shows the energy savings results.

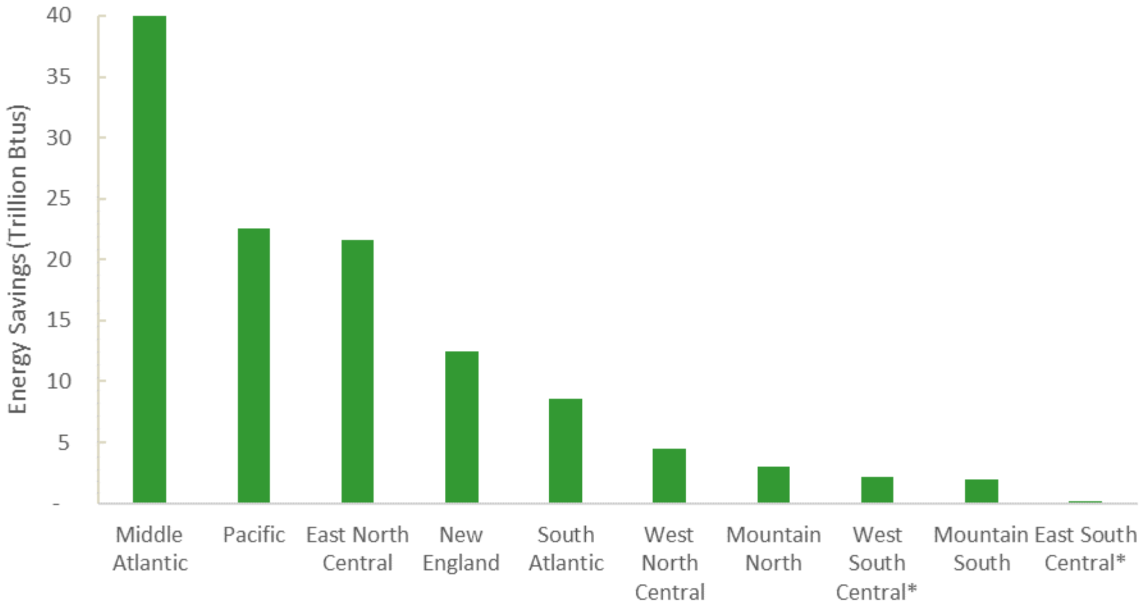

Figure 27. Total energy savings by region from installing a central heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced. *indicates low sample size (n<10)

Emissions

Following the same rankings as energy savings, the Middle Atlantic region has the highest potential for emissions savings, at nearly 2.8 million metric tons. It was followed by the Pacific (1.6 MMT), East North Central (1.5 MMT), and New England (8.7 MMT). Figure 28 shows the emissions by region.

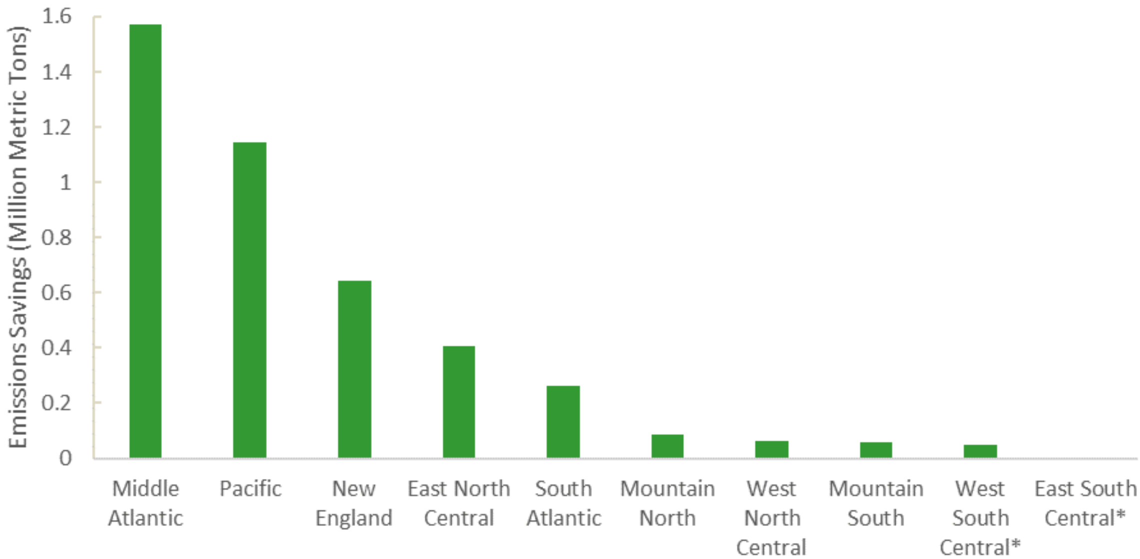

Figure 28. Estimated net emissions reduction by region from installing a central heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced. *indicates low sample size (n<10)

ECONOMICS

Much like the in-unit system results, central systems perform best in warmer climates, such as the South Atlantic, Mountain South, and Pacific, where payback hovers at around 30–40 years. In the remaining climates, the simple payback was extremely challenging, at more than 50 years (see figure 29).

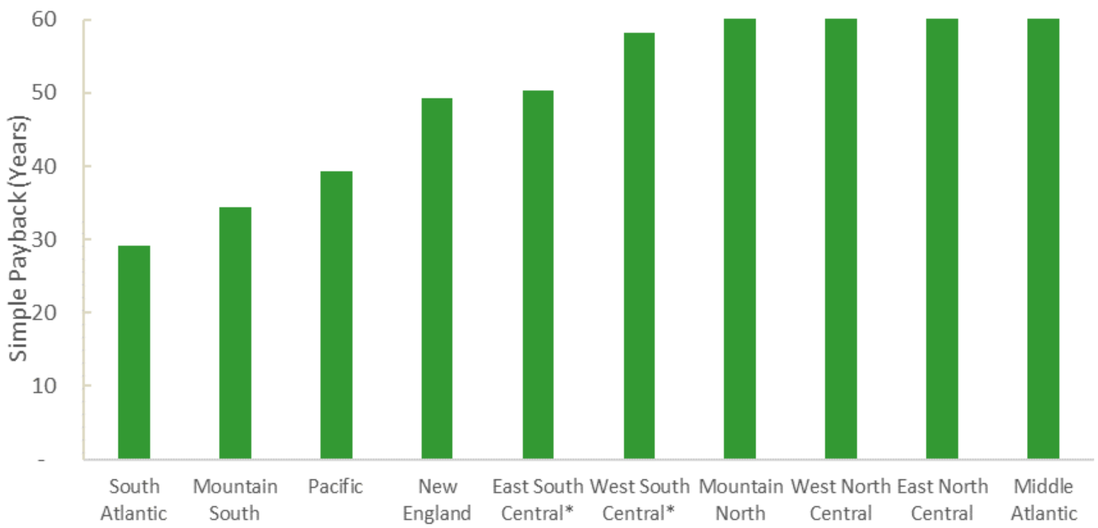

Figure 29. Average simple payback by region from installing a central heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced. This figure does not include the impact of incentives, load shifting, or carbon pricing. *indicates low sample size (n<10)

POLICY SCENARIOS AND SENSITIVITY ANALYSIS

As with the in-unit analysis, the central system analysis includes three policy scenarios: a utility incentive, load shifting, and a carbon price.[25] Because central HPWH systems are still early in their adoption process (even compared to in-unit systems), the "medium" installed cost is still relatively high. The combination of policy scenarios could help shift the medium cost closer to an aspirational lower cost once the market has matured. For instance, in the Pacific, the simple payback for the medium installed cost is 38 years, but the combination of the three policy scenarios reduces the simple payback to 12 years. One of the most obvious differences between the in-unit and the central system analyses is the economic benefit of load shifting, which we estimate to be four times higher for central systems, earning each apartment an additional $67.31 per year. From a thermodynamic standpoint, it is more efficient to heat one large tank of water than many small tanks to greater temperatures and

[25] For a summary of the sensitivity scenarios, see the sensitivity cases in the in-unit analysis discussion; for more details about our assumptions, see Appendix A.

the large central system tanks will better maintain that heat.[26] Figure 30 shows the policy scenario results.

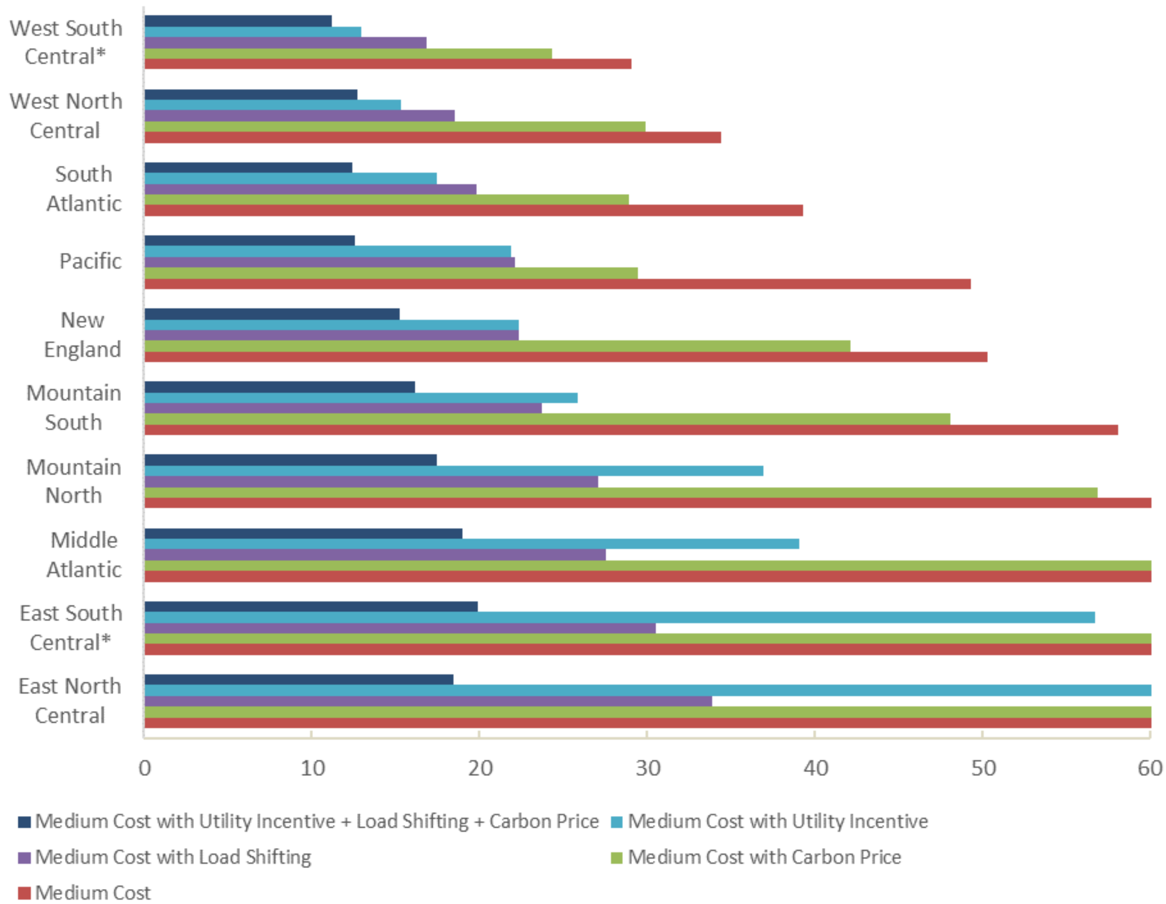

Figure 30. Average simple payback by region from installing a central heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced under different sensitivity scenarios. *indicates low sample size (n<10)

Also, like the in-unit analysis, this section includes an evaluation of the relative impact of the different variables when increased or decreased by 25%. Results show that the cost of natural gas has the greatest overall impact, followed by the efficiency of the heat pump systems, the incremental cost of the heat pump systems, and the cost of electricity. Although the policy scenarios, such as utility incentive and carbon price, were less sensitive than other variables, they have a greater ability to reduce first cost. The most pronounced example of this is the load-shifting scenario. Figure 31 shows the sensitivity analysis.

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[26] In addition, controls are simplified because there is typically one temperature setpoint to maintain, rather than many different setpoints.

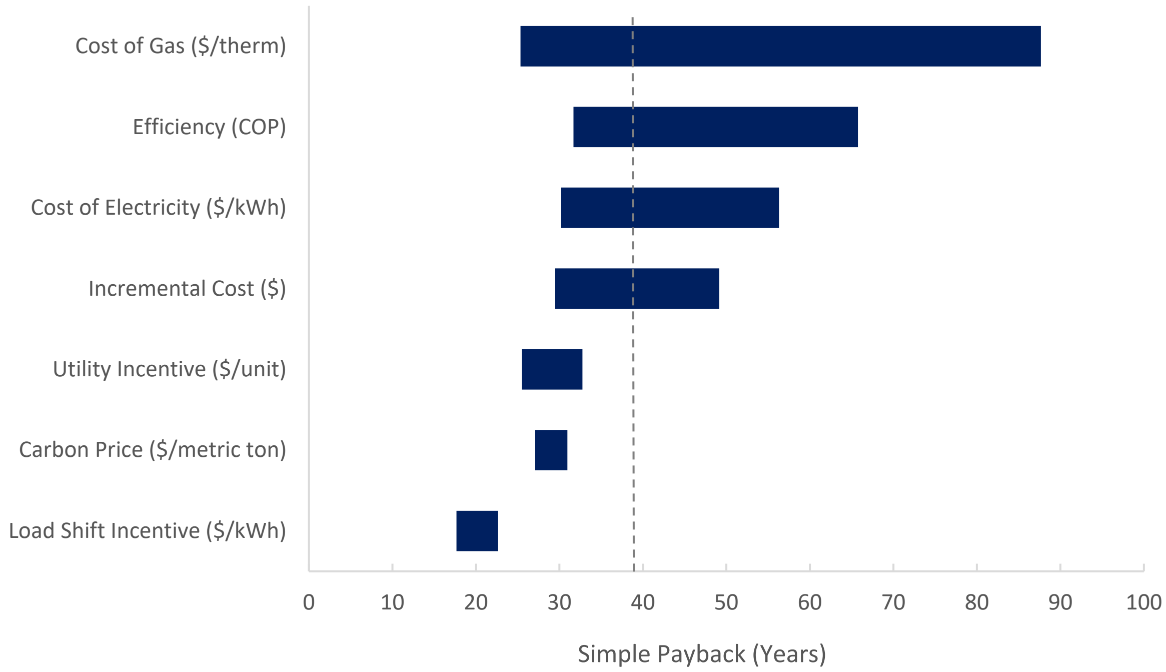

Figure 31. Sensitivity analysis illustrating relative impact of different variables from installing a central heat pump water heating system where an existing natural gas water heating system needs to be replaced. This sensitivity analysis is based in the Pacific region only, since some of the sensitivity cases in other climates resulted in some variables never paying back (which cannot be depicted graphically). The gray dotted line represents the average simple payback for an in-unit HPWH multifamily retrofit in the Pacific region (with no incentives) at 39.3 years.

Grid Flexibility

For central systems, designing the systems with oversized storage tanks can enable enough thermal storage capacity to support load shifting. As figure 32 shows, the central system analysis results show that the Middle Atlantic has the highest potential—to shift nearly 900 GWh of energy annually—followed closely by the Pacific region at about 750 GWh, and then the East North Central at 450 GWh.

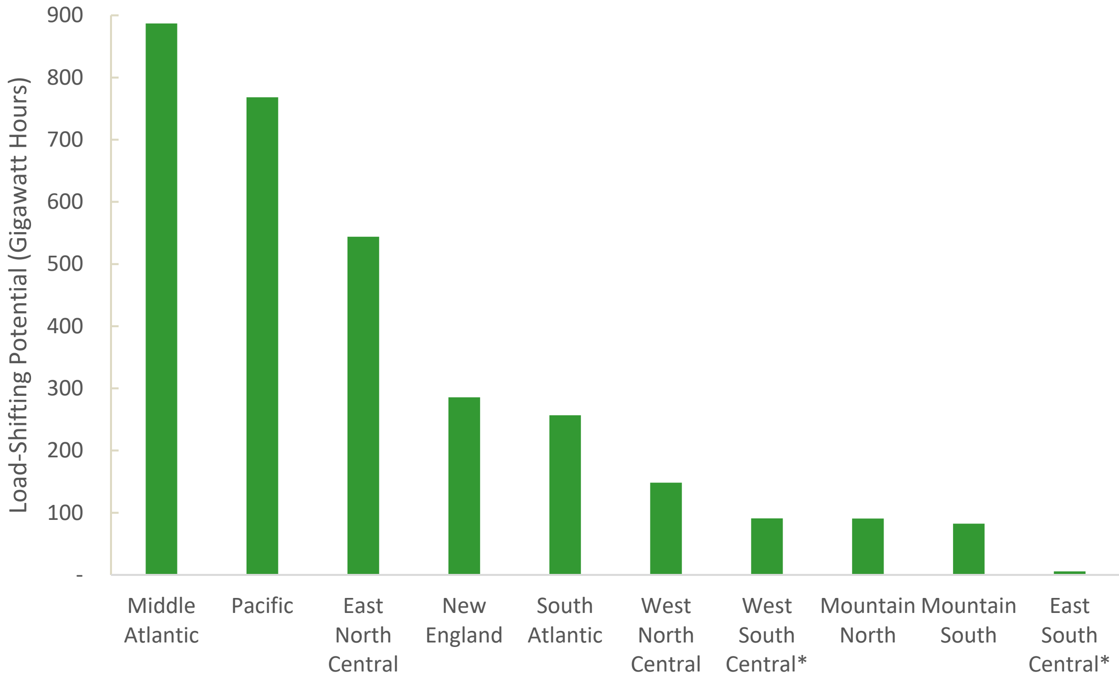

Figure 32. Total load-shifting potential by region from installing a central heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced. *indicates low sample size (n<10)

Combined Results

Generally, central systems had a much larger impact than in-unit systems in the multifamily sector, especially in the highest impact regions. Across both analyses, HPWH retrofits provided an average energy savings of 85% and GHG emissions savings of 58%. This results in a potential savings of 175 trillion Btus per year and 6.5 million metric tons of GHG emissions, as well as 3.5 terawatt hours of potential load-shifting benefits to the electric grid.

ENERGY SAVINGS

Given the combined results, it is clear that central systems have a greater influence than in-unit systems on energy savings in most U.S. regions. For instance, in the Middle Atlantic, the region with the highest potential for energy savings, central systems represent 83% of the energy savings. The 60/40 split in the Pacific is slightly more balanced, while East North Central is 72% in favor of central systems. These Middle Atlantic, Pacific, and East North Central could save 48 trillion Btus, 38 trillion Btus, and 30 trillion Btus, respectively. Figure 33 shows the combined energy savings.

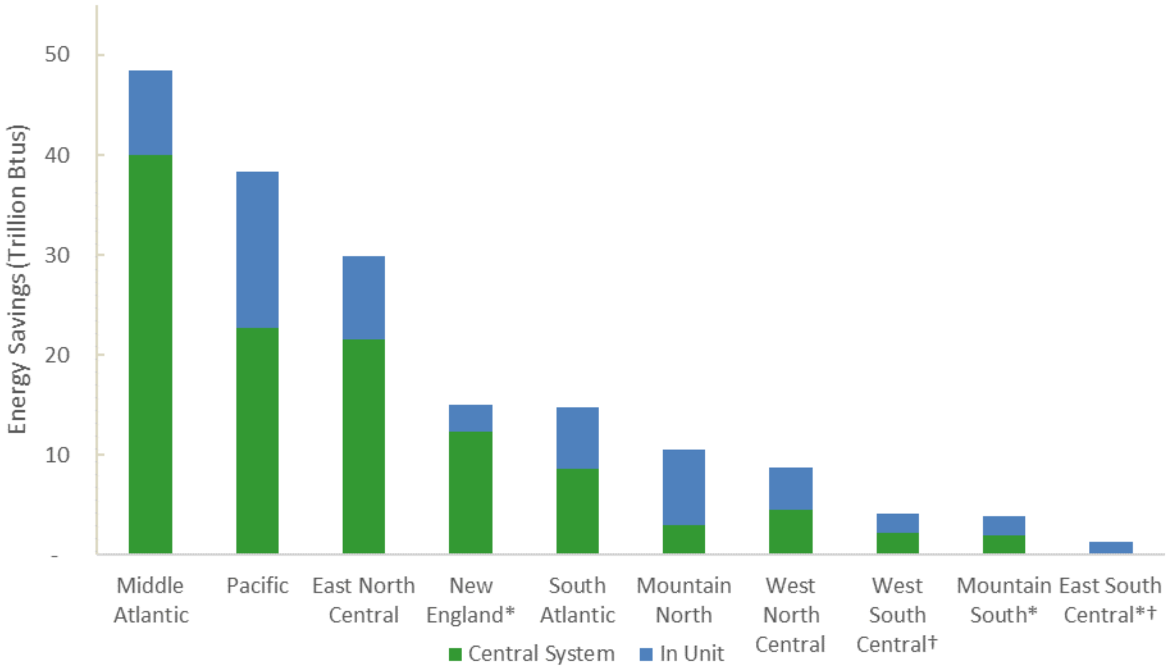

Figure 33. Total combined energy savings by region from installing in-unit and central system heat pump water heater (HPWH) systems where existing natural gas water heating systems needs to be replaced. *indicates low sample size for in-unit analysis (n<10) †indicates low sample size for central system analysis (n<10)

EMISSIONS

Central systems also have an outsized influence on emissions savings. Interestingly, the Pacific and Middle Atlantic are almost identical in their potential emissions savings—1.97 million and 1.94 million metric tons, respectively. However, as figure 42 shows, while approximately 40% of the Pacific's emissions savings are attributed to in-unit retrofits and 60% to central systems, the Middle Atlantic's emission savings are 80% in favor of central systems. Figure 34 shows the combined emissions results.

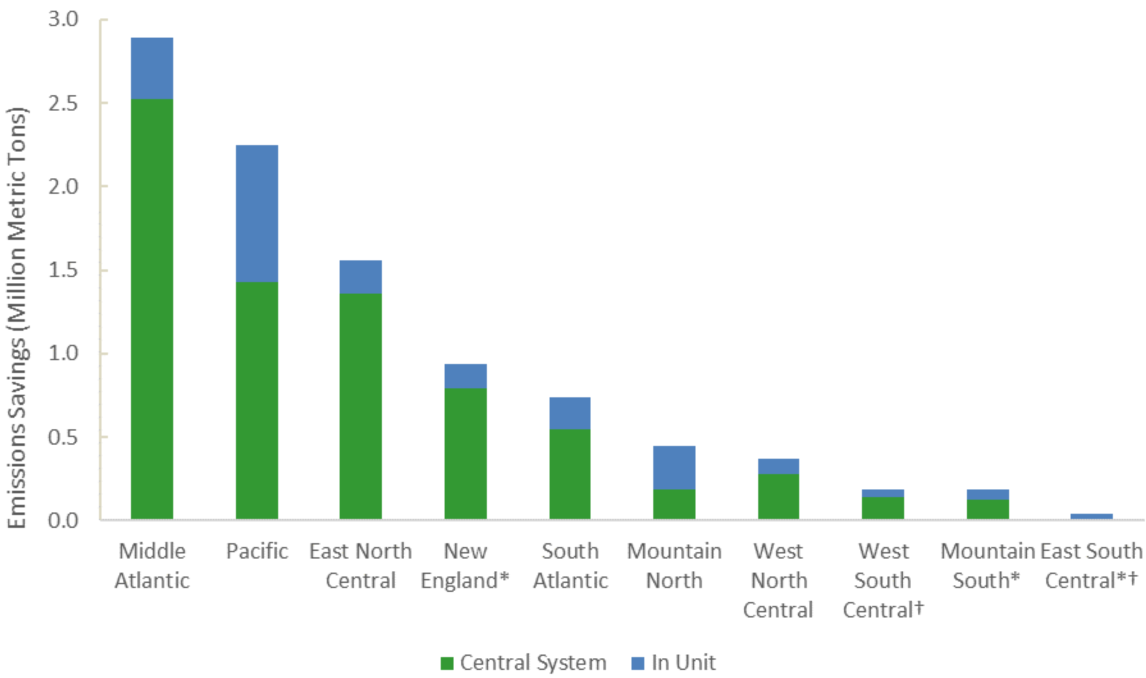

Figure 34. Estimated net emissions reduction by region from installing in-unit and central system heat pump water heater (HPWH) systems where existing natural gas water heating systems needs to be replaced. *indicates low sample size for in-unit analysis (n<10) †indicates low sample size for central system analysis (n<10)

Grid Flexibility

From a load-shifting potential, the Middle Atlantic region comes in on top, with more than 900 gigawatt hours of estimated annual grid benefits, and about 95% of that benefit coming from central systems. The Pacific is close behind at 870 GWh (88% from central systems) followed by East North Central at 600 GWh (91% from central systems). Figure 25 shows the load-shifting potential for in-unit and central systems.

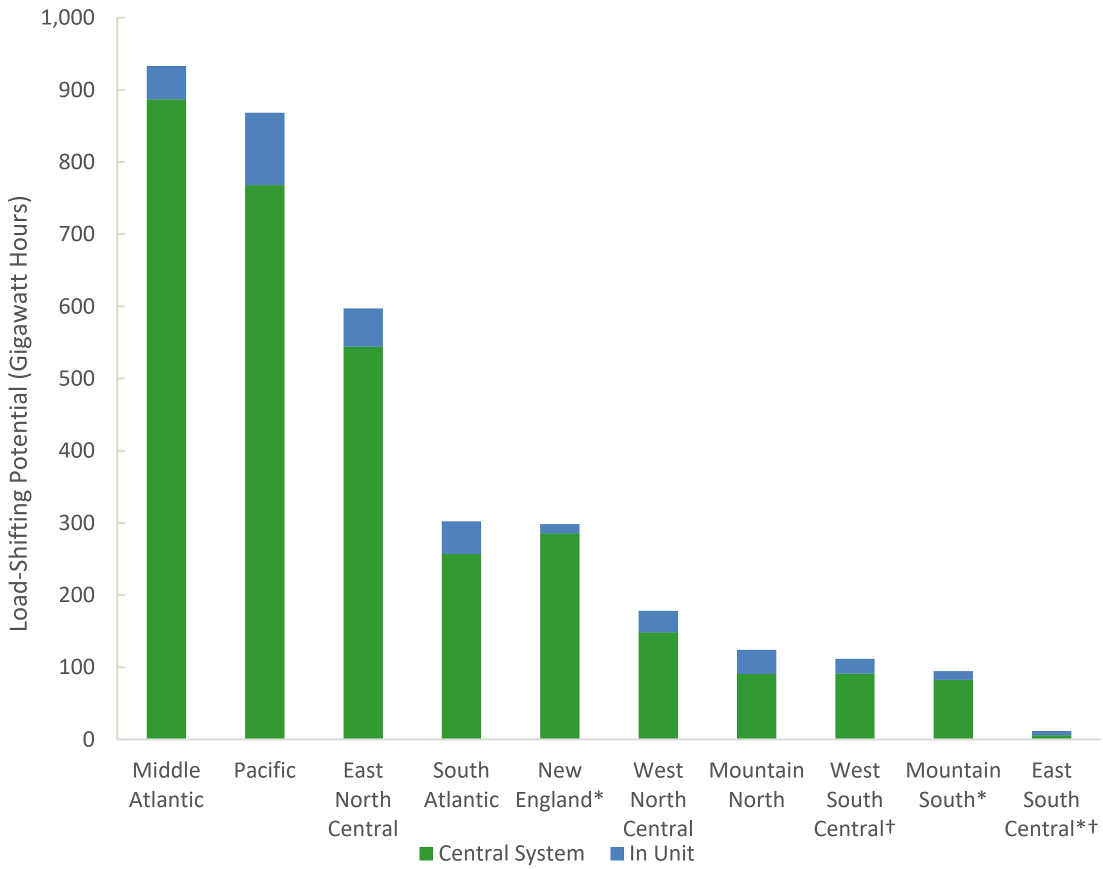

Figure 35. Total load-shifting potential by region from installing an in-unit and central system heat pump water heater (HPWH) systems where existing natural gas water heating systems needs to be replaced. *indicates low sample size for in-unit analysis (n<10) †indicates low sample size for central system analysis (n<10)

ENERGY BILL SAVINGS

One final result that may interest multifamily program implementers is the average raw energy bill savings on multifamily unit occupants from replacing existing minimally compliant gas water heater systems with HPWH systems. Note that these energy bill savings do not consider costs. Also, even within census regions, utility prices can vary wildly, and these numbers represent only the average savings. Without policy support, colder regions with higher-than-average electricity prices do not yield energy bill savings. Table 4 shows the estimated energy bill savings per unit.

Table 4. Annual energy bill savings per multifamily unit of heat pump water heater (HPWH) retrofit

Census region	No policies		Load shifting		Carbon price		Load shifting and carbon price	
	In-unit	Central system	In-unit	Central system	In-unit	Central system	In-unit	Central system
East North Central	$44	$21	$60	$88	$58	$33	$74	$101
East South Central*†	$114	$53	$130	$120	$120	$64	$136	$131
Middle Atlantic	No savings	$12	$8	$80	$25	$41	$41	$109
Mountain North	$25	$32	$40	$100	$34	$47	$49	$115
Mountain South*	$104	$79	$120	$146	$130	$90	$146	$157
New England*	No savings	$55	$1	$122	$15	$92	$30	$159
Pacific	$66	$69	$82	$136	$100	$93	$116	$160
South Atlantic	$113	$93	$129	$160	$136	$111	$152	$178
West North Central	No savings	$31	$9	$98	$4	$38	$20	$105
West South Central†	$63	$46	$79	$114	$89	$56	$105	$123

*indicates low sample size for in-unit analysis (n<10) †indicates low sample size for central system analysis (n<10)

Discussion and Recommendations

The U.S. HPWH market is still very much emerging. Although the technology for traditional in-unit products is fairly mature, they still represent only a fraction of the market, and 120-volt unitary systems and larger central systems are just starting to gain traction. There is an opportunity to take steps now to speed up the adoption of these low-energy, low-carbon, and grid-beneficial technologies. Providing guidance to the industry to properly design and operate this equipment will ensure that the benefits of these systems are fully realized, which will give the market confidence in the product. Different types of programs and policies can greatly help speed this transition. In addition, continued research and design can help improve the products currently on the market and provide additional affordable options for consumers and designers. The low-income market, which represents a sizeable portion of the multifamily market, should be another major area of focus, and it has its own unique challenges and opportunities. Finally, the water heating workforce, including plumbers and installers, will need tools to better understand HPWH systems—and the incentives to promote and install them.

SYSTEM DESIGN AND OPERATION

As the multifamily HPWH market matures, it is imperative to ensure that consistent HPWH system design and operation guidance are available to mechanical designers, plumbers, installers, building operators, and other relevant stakeholders. In-unit HPWHs have the potential to save significant energy and costs, but if installers place them in the wrong space or mode, they may end up using so much electric resistance to heat the water that it negates any potential energy cost savings. Further, while it seems counterintuitive, switching some units to "energy saver" or "hybrid" mode may result in significant electric resistance use, while "heat pump" mode uses little to no electric resistance.[27]

The increasing adoption of new electric technologies such as solar photovoltaics, electric vehicles, and heat pumps continues to change the grid's load profile, and it is becoming increasingly important for manufacturers to design HPWH systems with grid flexibility in mind. For both in-unit and central systems, part of their design strategy will be to ensure that the system includes connectivity and a mixing valve (if not already included within the HPWH unit) to ensure that the water delivered to occupants is the appropriate temperature. Further, while standard central system design offers a substantial potential for grid flexibility, engineers and mechanical designers should consider the potential demand flexibility benefits of oversizing the hot-water storage tanks. In space-constrained areas, however, the optimal design may be to install a smaller unit that uses a higher temperature setpoint.

Presently, designing cost-effective central multifamily HPWH systems with limited support from utility programs and state/local policies can be difficult. Over time, these programs and policies should help installed HPWH costs to decrease, which will help to increase the projects' cost effectiveness.[28] Until then, something such as a "dual fuel" or a "displacement" approach can help to bridge the cost-effectiveness gap.[29] Partial electrification systems are designed so that the heat pumps meet most of the load (e.g., 80%), and the remaining portion of the load is met with a natural gas system (or potentially with electric resistance). Using a natural gas water heating system in such cases lets the building rely on cheap gas when the electricity is very expensive; it also allows the designer to downsize the heat pumps, which greatly reduces initial costs compared to a 100% electric approach. Bright Power sees this approach as a transitional step to full electrification and suggests that "in the

[27] However, different manufacturers use different terminology, which further complicates this point.

[28] Ongoing costs are sometimes more cost prohibitive than initial costs, especially in areas like New York City, which has relatively unfavorable utility rates for electrification.

[29] These approaches are also sometimes referred to as "partial electrification" or "hybrid," although the term "hybrid" is somewhat overused in the energy industry and can lead to confusion.

future you can replace the gas with a multi-pass heat pump" (A. Nagengast, senior energy engineer, formerly of Bright Power, pers. comm., March 4, 2021).

Similarly, Steven Winter Associates has found that a displacement approach tends to work on its projects, which are primarily based in New York. In displacement projects, only part of the existing system is replaced by heat pumps—that is, heat pumps are "dropped in" as replacements for part of the gas system, which helps reduce up-front cost because there is no need to install redundant backup heat pumps since the gas system serves as a backup. In addition, the firm reports that the controls are much easier using the displacement approach because if problems occur, building occupants do not lose hot water (N. Ceci, principal mechanical engineer, Steven Winter Associates, pers. comm., March 4, 2021).

Case Study: Displacing Steam in a New York City Campus

Steven Winter Associates developed a displacement approach to help partially electrify a New York City campus's domestic hot-water system and reduce its dependency on district steam provided by Con Edison. The firm strategically designed an HPWH system to harvest the (substantial) heat generated in the steam room, and then exhaust cool air back to the room to help reduce the temperature. The HPWH system was able to displace roughly one-third of the hot-water load, while remaining cost effective for its client. Steven Winter Associates sees this type of project as a good "foot in the door" to start the process of electrification, with a goal to phase in more projects over time (Steven Winter Associates 2020).

Pairing an HPWH with other energy- and water-saving technologies and measures can also help increase energy bill savings and potentially make the economics more attractive. One low-cost example is an auto-diverting tub spout system. One study showed that it can save 7% of wasted water by letting the cold water drain at the beginning of the shower and then redirecting it to the showerhead once the water reaching the shower is hot (Sherman 2019). This greatly reduces the amount of hot water wasted down the drain while the occupant is doing something else, waiting for the water to heat up. Another energy-saving technology that is comparatively expensive and difficult to install as a retrofit is a drain-water heat recovery system, which captures thermal heat from shower drains and is used to preheat water for the water heater, reducing water heater energy consumption. Finally, recirculation system optimization can be a key complementary measure, and often consists of balancing the system, fixing crossover issues (i.e., imbalance between hot and cold water), insulating where possible, and slowing down the water to better maintain temperature (N. Dirr, director of programs, Association for Energy Affordability, pers. comm., August 23, 2021).

ENABLING PROGRAMS AND POLICIES

Although there does not appear to be a one-size-fits-all policy or program approach to best incentivize multifamily HPWH retrofits, one theme was consistent throughout our research and interviews: Incentives will need to be large to achieve meaningful scale.

Prior ACEEE research in the multifamily sector suggested that two of the most effective program approaches are to cultivate a long-term relationship with the property owner and offer flexible incentives on a variety of measures. ACEEE's report *Apartment Hunters: Programs Searching for Energy Savings in Multifamily Buildings*, recommends that program administrators provide a one-stop shop for program services, which gives property owners a dependable point of contact and source of technical assistance (Johnson 2013). Among other recommendations, the report suggests that program administrators provide escalating incentives for greater savings levels to encourage property owners to adopt a package of measures at one time. Programs should also be flexible and amenable to the capital constraints that multifamily property owners often face. For example, SMUD's program allows owners to take a staged approach and make improvements over a planned period of time. This allows owners who do not have the up-front capital for comprehensive retrofit to make upgrades as funds become available. Feedback from ACEEE's Multifamily Utility Working Group indicates that it can be difficult to get multifamily building owners to prioritize energy efficiency, making it critical to maximize the opportunity when working with them.

Technical assistance can provide value even beyond designing, installing, and maintaining a new HPWH system. The city of Berkeley, California, offers general guidance on its website for electrifying gas water heaters, including where to find all available incentives, guidance on permit and installation requirements, and links to other resources, including past webinars (City of Berkeley 2021). Direct technical assistance can also be used to overcome roadblocks that the property team may not anticipate, such as permitting. Through its 2020 Bay Area Multifamily Building Enhancements (BAMBE) program, the Association for Energy Affordability found that there may be "hidden costs and installation considerations" for its electrification projects. For example, building departments may have different requirements for outdoor compressor units, ranging from where the units can be installed to when shields are required (Dirr and Chitnis 2020).

A utility's or jurisdiction's priorities can help determine how it should structure its HPWH incentive. In areas with older multifamily building stock, HPWH installations likely will require electrical upgrades. Utilities should consider providing an electrical impact study to identify necessary upgrades—such as panel upgrades, wiring, and transformers—that will support increased electrical loads. They should also consider providing additional incentives for any necessary electrical upgrades. Utilities particularly concerned with grid interactivity might choose to incentivize only HPWHs with CTA 2045 ports or to cover the cost of installing a TMV (an enabling component for grid connectivity). The AWHI goes a step further and recommends that all programs should be, "planned with the knowledge that load-shifting controls will likely be required by regulations soon or in the future" (AWHI 2021a).

Different program types, such as upstream (manufacturers) or midstream/point-of-sale (wholesale suppliers or retailers), may be more effective for different products and regions. Midstream programs already exist in certain parts of the country for in-unit systems (e.g., Home Depot or Lowes receives the rebate). However, for central systems, it may make more sense to consider upstream programs for manufacturers and aggregators, since these systems are primarily custom built, and they are not carried by distributors. This trend may change once skid-mounted central systems become available and the norm. Additionally, providing at least a portion of incentive money directly to plumbers and installers for training and education could help them overcome the fear of the additional post-installation troubleshooting costs that are often associated with installing new technologies. Table 5 shows different components, services, and program types that utilities might consider for their multifamily HPWH programs.

Table 5. Possible opportunities for utility incentive programs

Opportunity	Category	Details
HPWH system	Component	Incentivize equipment to help reduce first costs
Grid connected HPWHs	Component	Incentivize only HPWHs that can be grid connected (i.e., through CTA 2045a or b)
Electrical panel upgrades	Component	If the building requires additional electric capacity, incentivize all or part of the upgrade
Electrical wiring	Component	Provide incentive for wiring needed during installation (e.g., wiring run from mechanical room to roof)
Transformers	Component	Provide incentive for transformer upgrades where needed
Thermostatic mixing valve	Component	Incentivize the installation of a thermostatic mixing valve or equipment that contains an internal mixing valve
Favorable time of use utility rates	Rate design	Develop rates that are more favorable to HPWHs, such as low electricity prices during times of low grid load
Technical assistance	Service	Offer complimentary technical assistance for installers and property teams
Electrical impact survey	Service	Evaluate the electrical upgrades needed to support increased electrical loads
Packaged offerings	Program type	Include HPWH as part of a larger package of available multifamily measures
Plumber and installer	Program type	Provide additional incentives for plumber and installer training and education

Opportunity	Category	Details
Upstream, midstream, or point-of-sale	Program type	Develop the best program for region and consider upstream, midstream, or point-of-sale programs

In addition to programs, policies can transform the market to support HPWH adoption. The federal government can offer consumer and manufacturer tax incentives to lower the cost of HPWHs. Raising federal efficiency standards can also benefit consumers. For both residential and commercial water heaters, setting higher efficiency requirements for all electric equipment can help steer the market from electric resistance water heaters to heat pumps. Similarly, raising the standards for all natural gas water heaters to at least 90% thermal efficiency (i.e., condensing level) can help make the equipment costs between gas and HPWHs more comparable. Currently, only large residential tank water heaters (i.e., 55 gallons or more) must meet heat pump and condensing efficiency levels.

State and local governments can also enact policies that encourage HPWH adoption. For example, they can update their building codes to encourage HPWH installation. They can also pursue methods of incorporating electrification into their building codes, such as by enacting natural gas bans for new construction. States and localities can also create HPWH incentive programs like the California Self Generation Incentive Program and BayREN's BAMBE program. States and jurisdictions may want to consider establishing such programs if federal funding becomes available through infrastructure or stimulus bills. In addition to incentives and rebates, states and localities can provide tax incentives, streamlined permitting, and financing programs to encourage HPWH adoption.

Utility regulators can also update and establish regulations to support HPWHs. They can encourage or require utilities to provide TOU pricing, which can improve the economics of grid-connected HPWHs. In addition, they can revise fuel-switching regulations to allow for electrification programs that provide incentives for measure that require switching from gas to electric.

FUTURE RESEARCH AND DESIGN

New types of HPWH systems coming to the U.S. market can help overcome some of the design constraints of existing systems on the market. For instance, 120-volt HPWHs can help eliminate the need for additional electrical capacity in retrofit projects, while also taking up a smaller footprint than 240-volt HPWHs in space-constrained applications. For central systems, skid-mounted HPWHs can help reduce the complexity of sizing and installing these systems, making central systems more widely accessible for large multifamily applications. Manufacturers and research labs should continue to conduct research and design to further innovate these products, especially for the colder climates in the U.S. market.

Some products that exist elsewhere could make a major impact if introduced to the U.S. market. For instance, a small wall-mounted HPWH could be a great solution in space-constrained markets such as low-income multifamily. Such a product exists in other countries—see the unit in figure 36, for example—but is not currently available in the United States (P. Delforge, senior scientist: Building Decarbonization, Climate, and Energy Program, Natural Resources Defense Council, pers. comm., April 23, 2021).

Figure 36. The Ariston Lydos Wall-Mounted Heat Pump Water Heater (not yet available in the United States). Source: Enercom 2019.

In addition to designing more compact products, the industry would benefit if more types of HPWHs were available for different climates and applications. As we noted earlier, different refrigerants and system configurations (i.e., multi-pass versus single pass) have tradeoffs. Some systems may have an advantage in cold climates, while others have an advantage with a warm incoming water temperature. With more options available on the market, mechanical designers can design the best systems to meet the needs of multifamily buildings with a variety of design considerations. In addition, hybrid heat pump systems that can provide both water heating and space heating to a building could play a major role in future electrification upgrades.

The U.S. grid system would benefit greatly from integrated TMVs in in-unit HPWH systems to ensure that HPWHs can contribute to grid flexibility. It costs approximately $250–400 for a plumber to install an external mixing valve during an HPWH installation (N. Dirr, director of programs, Association for Energy Affordability, pers. comm., August 23, 2021); to cut costs, many building owners will likely forgo mixing valve installation. Manufacturers can take the uncertainty out of the process by making TMVs the default option in their units.

The market could also greatly benefit from more research on in-unit ventilation. Currently, manufacturer and incentive program guidelines strongly recommend not allowing the HPWH to vent cold air directly into the apartment because of potential thermal comfort impacts and additional heating requirements. However, additional studies could help determine if there are acceptable scenarios in which venting has a minimal effect (e.g., perhaps the cooling impact is acceptable in a 1,000-square-foot apartment, but not in a 500-square-foot apartment). Additionally, there may be best practices for venting that could apply to many different types of multifamily dwelling units, such as venting in a laundry room or behind a refrigerator, which both expel heat.

Providing more (and cheaper) options for in-unit and central split systems to operate in cold temperature applications will help open up a much larger market for these products. Currently, the main option for HPWHs in cold ambient temperatures (such as those lower than 40˚F) is CO_2-based models. However, models with other refrigerants, such as R134a, could potentially design their systems to do the same. Much like air source heat pumps that operate at cold temperatures, HPWHs can be designed to include a defrost cycle that temporarily operates the heat pump in reverse to remove frost from the coil, which would otherwise degrade the heat pump's efficiency.

CONSIDERATIONS FOR AFFORDABLE HOUSING

Affordable and market-rate multifamily buildings share many of the same problems and constraints, which are often amplified in affordable housing. One of the biggest differentiators is that affordable housing units are typically more densely packed (e.g., 500–600 square feet per apartment) than market-rate units. Space is thus at a premium in affordable housing apartments. New options, such as the 120-volt HPWH, may be a great retrofit choice, as might the even more compact units that are not yet on the market (e.g., the wall-mounted unit described in the Future Research and Design section). Often, affordable housing properties also have limited access to capital for property upgrades and lack the staff expertise required to maintain and operate more complex mechanical systems.

On the other hand, one potential advantage for subsidized affordable housing is that property owners often hold onto their buildings longer than market-rate owners. Commercial real estate owners often sell their assets after only a few years and may operate on a short time horizon for projects (such as two to three years), while subsidized low-income multifamily owners tend to hold onto their assets longer and may be able to consider projects with a much longer timeframe (such as 10 to 15 years) (S. Samarripas, local policy manager, American Council for an Energy-Efficient Economy, pers. comm., May 14, 2021). This could enable challenging HPWH retrofits in subsidized affordable housing properties that would not be possible in similar market-rate buildings.

Unsubsidized (or *naturally occurring*) low-income housing can be more challenging. These properties tend to be smaller and owned and managed by individual investors (i.e., "mom and pop" landlords) rather than professionally managed. Past ACEEE research found that while the small scale of these properties increases the difficulty of acquiring energy efficiency investments, "coordinating energy efficiency investments with other projects or at times of refinancing can motivate building owners and managers to participate in energy efficiency programs" (Samarripas, York, and Ross 2017).

Multifamily HPHW programs can include designs to protect renters from increased costs from HPWH retrofits. NYSERDA's Multifamily Performance Program Heat Pump Demonstration project requires participants to submit an energy savings and rent affordability plan that explains how they will avoid increasing housing costs for tenants, particularly if the tenants are responsible for electricity costs (NYSERDA 2021). Participants are also required to certify that they will not raise rents for at least two years after the construction is completed. However, they also grant allowable factors for rent increases that are not associated with increased energy costs or property value from the retrofit, including increases in property taxes and increases in maintenance or operating expenses.

WORKFORCE AND CONSUMER EDUCATION

As with any technology in the early stages of the market transformation process, education and training are key to ensuring the industry understands how to install and operate the technology so that it achieves optimum performance. Lessons learned from the residential water heating sector show that plumbers and installers are accustomed to emergency replacements of water heating systems. In these scenarios, a customer's water heater fails and they request a quick replacement to enable continued access to hot water. In almost all scenarios, the plumber will do a like-for-like replacement, such as swapping a failed 50-gallon natural gas water heater for a new comparable 50-gallon natural gas water heater.

As a result, proactive water heating replacement is relatively rare in the hot-water industry, while switching fuel types is all but unheard of in most parts of the country. Since mechanical designers, plumbers, and installers lack familiarity with this type of retrofit, they may be reluctant to take it on. As we discussed earlier, HPWHs present different considerations relative to natural gas water heaters; these considerations ranging from providing adequate airflow to correctly sizing the system. To compensate for the uncertainties, installers may mark up their initial installation cost estimates well beyond what they would for a like-for-like replacement.

Providing training and education can help the designer, plumber, and installer groups develop a greater understanding of and comfort with HPWH design and installations. This, in turn, can help drive down the initial installation costs and improve system operation and maintenance (because the technicians better understand HPWH systems and how to resolve potential issues). Tools, such as Ecotope's Ecosizer,[30] that provide guidance for central HPWH system sizing also offer much needed guidance for the industry. Providing HPWH-specific training, and possibly certifications, for installing, commissioning, and operating equipment could also help the industry better adapt to these changes.

SUBSECTORS TO TARGET FIRST

With so many considerations for multifamily HPWH retrofits, it can be helpful to identify characteristics of those multifamily properties that are most likely to adopt HPWH

[30] Explore this tool at ecosizer.ecotope.com/sizer.

technologies. These property types can be potential first movers while the market for these products is still relatively small.

Privately owned multifamily buildings may be a good target for HPWH retrofits, depending on the owner's goals. Because many large multifamily buildings that are owned by real estate investment trusts (REITs) are currently return-on-investment (ROI) driven, they are unlikely to adopt a new energy efficiency technology unless it has an extremely attractive ROI (e.g., five years or less). These properties are bought and sold so rapidly that projects with longer-term paybacks—such as HPWH retrofits—are often nonstarters. That said, properties owned by a company that is committed to energy or GHG reductions could be a strong target for adoption, especially when paired with strong program and policy support. These companies also tend to hold onto properties longer than average.

Small and medium multifamily buildings, including subsidized affordable housing properties, also may be more likely to commit to an HPWH retrofit project. Through its work with many multifamily electrification programs with HPWH offerings, AEA has found it is especially helpful to find an efficiency champion at the property. This champion will be invested in the energy and environmental benefits of HPWHs and willing to take the risk and do something different (N. Dirr, director of programs, Association for Energy Affordability, pers. comm., April 13, 2021).

Although New York City's electricity prices rank among some of the highest in the nation—which can make electrification challenging—it can provide helpful indicators for the rest of the country. Urban Green Council's evaluation of New York City's market resulted in the recommendation to use three criteria that indicate whether a privately owned building is a good initial target for electrification. These criteria recommend targeting buildings that: use a costly fuel (i.e., electric resistance, fuel oil, or district steam); use one-pipe steam heating systems (which is more relevant for space heating upgrades than water heating); and are owned by the tenant (e.g., a condo or co-op). The first two recommendations are directly related to improved economics. The rationale for the third recommendation about occupant-ownership is that it helps to "avoid issues that arise in rental buildings, such as resistance to submetering and billing directly for heating use,"[31] which could be an issue in any part of the country. The Urban Green Council's report also suggests that heat pump technologies first be demonstrated through pilot projects in city- and state-owned buildings, such as New York City Housing Authority apartments (Urban Green Council 2020).

[31] On the other hand, major investment decisions for co-ops and condos are often made by co-op or homeowners association boards, which can be reluctant to engage in large-scale electrification projects. Rental owners frequently have more flexibility to make these decisions and may be better targets (N. Ceci, principal mechanical engineer, Steven Winter Associates, pers. comm., August 20, 2021).

Conclusion

HPWHs can help provide energy savings, carbon reductions, and grid benefits to the multifamily sector. However, the multifamily HPWH market is still rapidly evolving, and substantial policy interventions, financial incentives, and technical assistance will be critical to help increase market uptake more quickly in this sector. Whereas incentives can help reduce the initial first cost, updated utility rates that value grid benefits can help improve ongoing costs. Both in-unit and central system retrofits have their own advantages and disadvantages, but both can be feasible options. For instance, the average cost of in-unit retrofits is lower than central systems; however, finding a way to adequately ventilate these units can be a challenge. While central system retrofits can be more costly up front, they also offer greater potential for grid flexibility benefits, which is becoming increasingly important to utilities to ensure grid stability.

The HPWH market itself is undergoing significant changes, and manufacturers are in the process of developing new HPWH designs, many of which also use low global warming potential (GWP) refrigerants. The market will greatly benefit from having more available (and affordable) options that can be used in more applications. For in-unit retrofits, new 120-volt HPWHs will not require additional electrical upgrades; for central systems, skid-mounted systems will make installation significantly easier for installers and contractors. In the interim, partial electrification (e.g., using dual fuel systems or a displacement approach) can help reduce dependency on fossil fuels, while still allowing projects to remain cost effective, especially in colder parts of the country and areas with high electricity prices and low natural gas costs.

Cities, states, and utilities interested in reducing carbon emissions and enhancing grid flexibility in multifamily buildings should consider the benefits of HPWH retrofits. A combination of strong programs and policies can help make this transformation a reality.

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Appendix A. Methodology and Assumptions

This appendix documents the methodology we used to conduct the energy, emissions, economics, and grid analyses for our study.

For both the in-unit and central system analyses, we evaluated replacement of the existing natural gas water heating system with a heat pump water heating (HPWH) system. We assumed that the alternative to the heat pump system was to replace the existing natural gas system with a similar natural gas system. Since equipment standards have not significantly improved the efficiency of natural gas water heating systems (e.g., condensing levels) over the past decade, we assumed that a replacement system would perform similarly to the existing system, resulting in similar energy consumption and costs.

A major consideration when using the Residential Energy Consumption Survey (RECS) database is that all multifamily data are provided as "per unit" rather than "per building." Additionally, RECS lacks sufficient information about overall multifamily building size, making it impossible to know from the RECS data how many units are inside each building. As a result, our analysis was largely conducted on a per-apartment basis, using RECS weighting factors to estimate the representativeness of each apartment in each region. While there are advantages to conducting the analysis in this way, a major disadvantage is that we were unable to differentiate among different multifamily building sizes.

Because heat pump systems can remain in buildings for one to two decades, we used future projections of energy costs. Using 2030 data let us remain consistent with our methodology for *Electrifying Space Heating in Commercial Buildings: Opportunities and Challenges* (Nadel and Perry 2020). For energy prices, we used site-specific energy costs in 2015 for each building and then adjusted for regional electricity and natural gas price trends from 2015 to 2030 per EIA's *Annual Energy Outlook* data (EIA 2021a). Table A-1 shows these prices.

Table A-1. Average 2015 and average projected 2030 residential building energy price comparison

Fuel	2015 residential price	Projected 2030 residential price	Adjustment factor
Electricity	$0.1265 per kWh	$0.1247 per kWh	–1.45%
Natural gas	$10.38 per thousand cubic feet	$10.60 per thousand cubic feet	+2.11%

Source: EIA 2021a

Adjusted price data from the RECS database shows that the Middle Atlantic and New England regions have much higher average electricity costs than the rest of the country. While natural gas costs are more consistent, the West North Central and Mountain North are a bit lower than the average. Table A-2 shows these data.

Table A-2. Average projected 2030 commercial-building energy price comparison

Region	Average projected 2030 electricity costs ($/kWh)	Average projected 2030 natural gas costs ($/therm)
East North Central	$0.1488	$1.1169
East South Central	$0.1128	$1.3001
Middle Atlantic	$0.2310	$1.3109
Mountain North	$0.1335	$1.0355
Mountain South	$0.1415	$1.5972
New England	$0.2156	$1.3678
Pacific	$0.1459	$1.4466
South Atlantic	$0.1338	$1.4719
West North Central	$0.1408	$0.9734
West South Central	$0.1196	$1.3479

Source: Calculated from EIA 2016 and EIA 2021a

For our carbon-pricing scenario, we assumed a $50/ton fee on carbon dioxide emissions and on both natural gas used in gas water heating systems and fossil fuels used to generate electricity. We used a nationwide average of natural gas emissions (EIA 2016) for fossil fuels and 2030 regional projections for electricity emissions from the grid (see table A-3) (EIA 2021a).

Table A-3. Natural gas and electricity emissions assumptions

Region	Emissions type	Metric tons of CO_2 per kBtu
All	Natural gas	0.0000531
East North Central	Electricity	0.0000386
East South Central	Electricity	0.0000460
Middle Atlantic	Electricity	0.0000239
Mountain	Electricity	0.0000320
New England	Electricity	0.0000114
Pacific	Electricity	0.0000130
South Atlantic	Electricity	0.0000355
West North Central	Electricity	0.0000433
West South Central	Electricity	0.0000391

Source: Calculated from EIA 2016 and EIA 2021a

IN-UNIT ANALYSIS

The RECS database contains 192 sample dwelling units with in-unit natural gas water heaters. Since the database does not include efficiency ratings, we assumed all systems had an efficiency of 0.63 UEF, which is the average unitary natural gas water heater efficiency from the extensive DOE eeCompass database (DOE 2021). The eeCompass database shows the average HPWH efficiency as 3.11 UEF. However, because HPWH efficiency is highly dependent on ambient air temperature, we adjusted for each census region. We used an NRDC/Ecotope database of HPWH performance data by state to create adjustment factors for each census division, as table A-4 shows (NRDC and Ecotope 2016).

Table A-4. Estimated in-unit heat pump water heater efficiency by census region

Census region	Average annual UEF
West North Central	2.67
East North Central	2.75
New England	2.77
Mountain North	2.81
Middle Atlantic	2.98
Average	3.11
South Atlantic	3.33
East South Central	3.38
Pacific	3.43
West South Central	3.47
Mountain South	3.51

Source: Calculated based on data from DOE 2021 and NRDC and Ecotope 2016

We assumed the average replacement cost of an in-unit natural gas water heater to be $1,439, which is an average for residential installation taken from sources including This Old House, Home Advisor, Home Depot, and Home Guide; we used this average as a proxy for the multifamily sector as there is a lack of available data on multifamily installation costs (This Old House 2021; Home Advisor 2021; Home Depot 2021; Home Guide 2021). We assumed an in-unit HPWH installation cost of $3,500 per unit (resulting in an incremental cost of $2,061 per unit) based on estimates from our data partners and Silicon Valley Clean Energy (SVCE 2021). Based on our conversations with system designers/implementers, this cost represents a multifamily HPWH retrofit project that includes plumbing and piping, some ventilation (e.g., louvers or ducts), and the installation of a standard dedicated electrical circuit. Beyond the electrical circuit, this cost does not include the cost of electrical upgrades such as an upgraded subpanel or any other upgrades upstream of the panel. Insufficient data were available to understand how frequently additional electrical upgrades are required, so this cost best represents scenarios in which additional electrical upgrades are either not needed or are largely covered by utility program incentives.

Our incentive policy scenario assumed $800 per water heater, based on a rough midpoint of the different in-unit water heater incentives detailed in table 3 in the body of the report.

For the load-shifting scenario, we assumed that events would occur during the winter and summer during weekdays (and not on weekends or during the shoulder seasons); this translated to approximately 130 days per year. This scenario does not represent common current practice but instead represents a hypothetical future scenario in which events are called this frequently. We assumed that load-shift events would occur for three hours per day, a rough midpoint based on a Bonneville Power Administration (BPA) load-shifting study (Eustis and Koch 2018). Using the same study, we also assumed that in-unit water heaters could shift approximately 200 watt-hours each hour on average. The load-shifting incentive was assumed to be $0.20 per kWh in 2030, which was a low-end conservative estimate based on current time-of-use (TOU) rates from Southern California Edison and Hawaiian Electric (SCE 2021; Hawaiian Electric 2021), since California and Hawaii have a larger presence of solar photovoltaics than most other parts of the country and place a greater emphasis on demand flexibility.

We also included a mini analysis of the replacement of unit electric resistance water heaters with HPWHs. The RECS database contains 370 apartment units with in-unit electric water heaters. Given the low market penetration of HPWHs in the multifamily sector, we assumed all electric water heaters were electric resistance, but it is possible that some are already HPWHs (RECS does not differentiate between the two). This analysis included an assumption of 0.92 UEF for electric resistance, based on the average unitary electric resistance water heater efficiency from the DOE eeCompass database (DOE 2021). We assumed $800 as an average incremental cost, based on assumptions from the ENERGY STAR program (EPA 2021c). For the remaining assumptions—such as HPWH efficiencies and electricity rates—we used the same assumptions as the in-unit natural gas analysis. We did not conduct a similar electric resistance replacement study for central systems, as they represent a much smaller subset of the multifamily sector.

CENTRAL SYSTEM ANALYSIS

The RECS database contains 357 sample dwelling units with central systems. We assumed the baseline natural gas system to have a 0.59 coefficient of performance (COP) value. While large natural gas water heater and boiler systems typically use thermal efficiency as a metric, this metric cannot be used to represent HPWH performance. We therefore determined that COP was the best metric to directly compare both HPWH and natural gas central systems. Since COP is typically used to describe heat pump performance, it was difficult to find data on the typical natural gas metric represented in COP. However, we did find one study on residential systems that provided a 0.59 COP value for natural gas systems, and we used this number for the central system evaluation (Colon 2017).

As outlined in the Central Systems section, we assumed that the central HPWH system would include both a primary heat pump and a temperature maintenance system. The primary system was assumed to be a CO_2-based single-pass system. Using the only CO_2 system currently available in the U.S. market, we correlated a SanCO_2 (which can be ganged together to create a primary central system) performance curve (see figure A-1) with the average ambient outdoor temperature (at 150˚F outlet water temperature), resulting in a COP of 4.13–4.62 depending on climate for the primary heat pump. However, we assumed the temperature maintenance system would be much lower efficiency, an average of 2.0 COP, due to high use of electric resistance. When combined, with the primary system representing two-thirds of energy use and temperature maintenance representing one-third, the system COP ranged from 3.42 to 3.74.

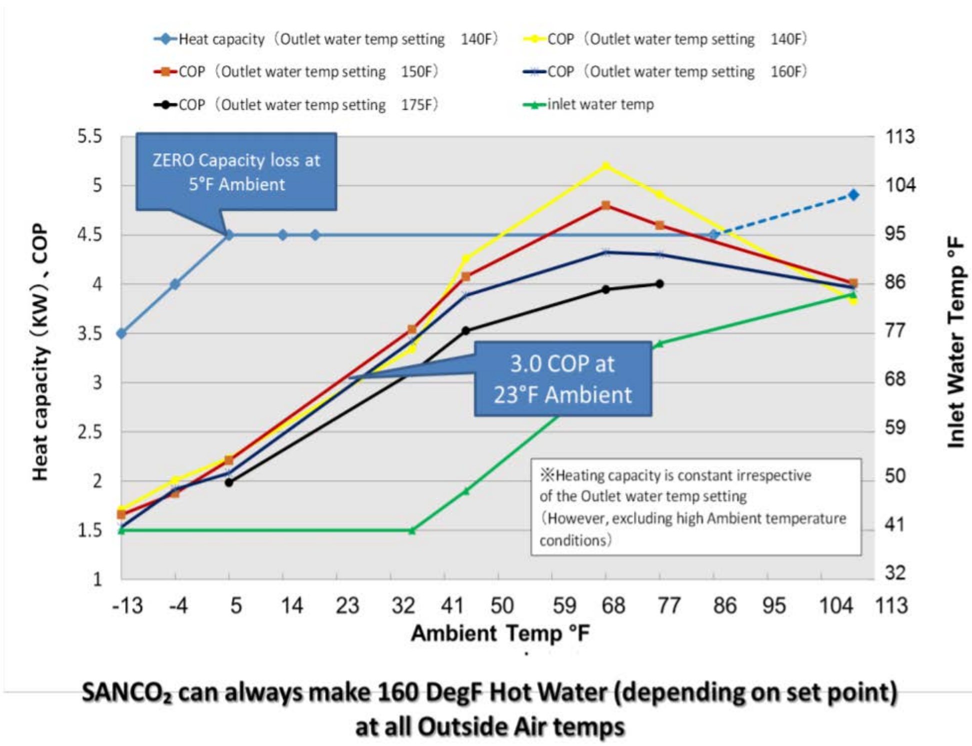

Figure A-1. SanCO_2 capacity and efficiency versus ambient air temperature. Source: Miles, Ito, and Hale 2017.

We estimated the cost to install a replacement central natural gas boiler or water heater to be $300 per unit, based on feedback from our data partners, who noted that the cost of natural gas retrofits was a fraction (often just 10%) of the cost of an HPWH retrofit. Based on this feedback, we estimated the average cost of a HPWH retrofit to be $3,000, resulting in an incremental cost of $2,700 per unit. This cost represents an average between small central packaged systems, which tend to cost $2,000–3,000 per unit, and central split or ganged systems, which cost between $3,000–4,000 per unit. The average cost per apartment unit for BPA's Elizabeth James House central system HPWH retrofit was $2,711 (HDC 2021). Beyond the electrical circuit, this cost does not include the cost of electrical upgrades (such as an upgraded subpanel or any additional upstream upgrades). Insufficient data were available to understand how frequently additional electrical upgrades are required, so this cost best represents scenarios in which additional electrical upgrades are either not needed or are largely covered by utility program incentives.

The incentive policy scenario assumed $1,000 per water heater, based on a rough midpoint of the different in-unit water heater incentives detailed in table 4.

For the load-shifting scenario, we assumed that events would occur during the winter and summer during weekdays (and not on weekends or during the shoulder seasons), which translated to approximately 130 days per year. We assumed that load-shift events would occur for three hours per day, which is a rough midpoint based on a BPA load-shifting study (Eustis and Koch 2018). Feedback from data partners suggested that the load-shifting potential for central systems is 70% of the unit's capacity (without oversizing the system). Using the Ecosizer tool with default settings, we estimated the central system capacity to be 1.23 kWh per unit on average. The load-shifting incentive was assumed to be $0.20 per kWh, which was a low-end conservative estimate based on TOU rates from Southern California Edison and Hawaiian Energy, since California and Hawaii have a larger presence of solar photovoltaics than most other parts of the country and place a greater emphasis on demand flexibility.

Appendix B. Additional Policy Analysis Scenarios by Region and Climate Region

While census region subdivisions can be useful, other ways of dividing the country may be more applicable in some scenarios. In addition, fewer subdivisions also help researchers overcome the small sample size issue in some census regions. Ideally, future studies will provide an even more granular snapshot, such as at the state or utility level. For this study, however, we provide two other subdivisions—by region and climate region—as we now describe.

IN-UNIT

Dividing the country into quadrants—South, West, Midwest, and Northeast—yields at least 21 data points per region, resulting in a smaller margin of error. However, the regional utility price and climate trends seen in the census region subdivisions are much more diluted. Figure B-1 shows the policy analysis results using the region subdivisions.

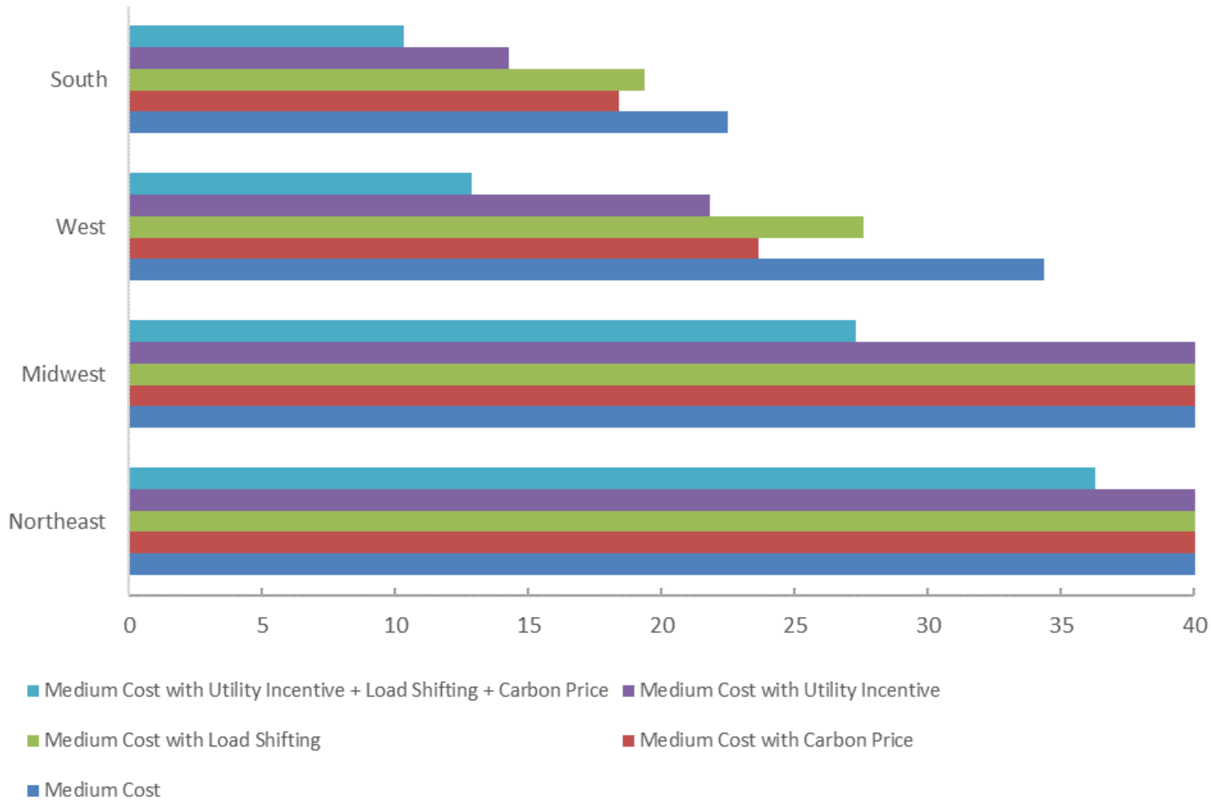

Figure B-1. Average simple payback by region from installing an in-unit heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced under different sensitivity scenarios

Dividing by climate region (figure B-2) can help capture the HPWH performance relative to climate; however, it does not effectively capture regional utility price trends.

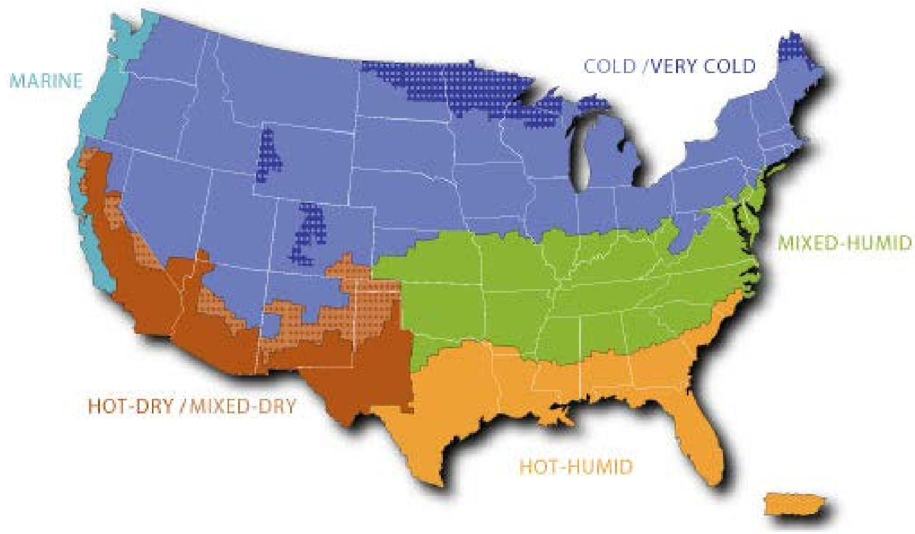

Figure B-2. Building America Climate Regions. Source: EIA 2021c.

Figure B-3 shows policy analysis results by climate region, with relatively consistent results for hot, mixed, and marine climates, while cold/very cold climates result in more challenging economics.

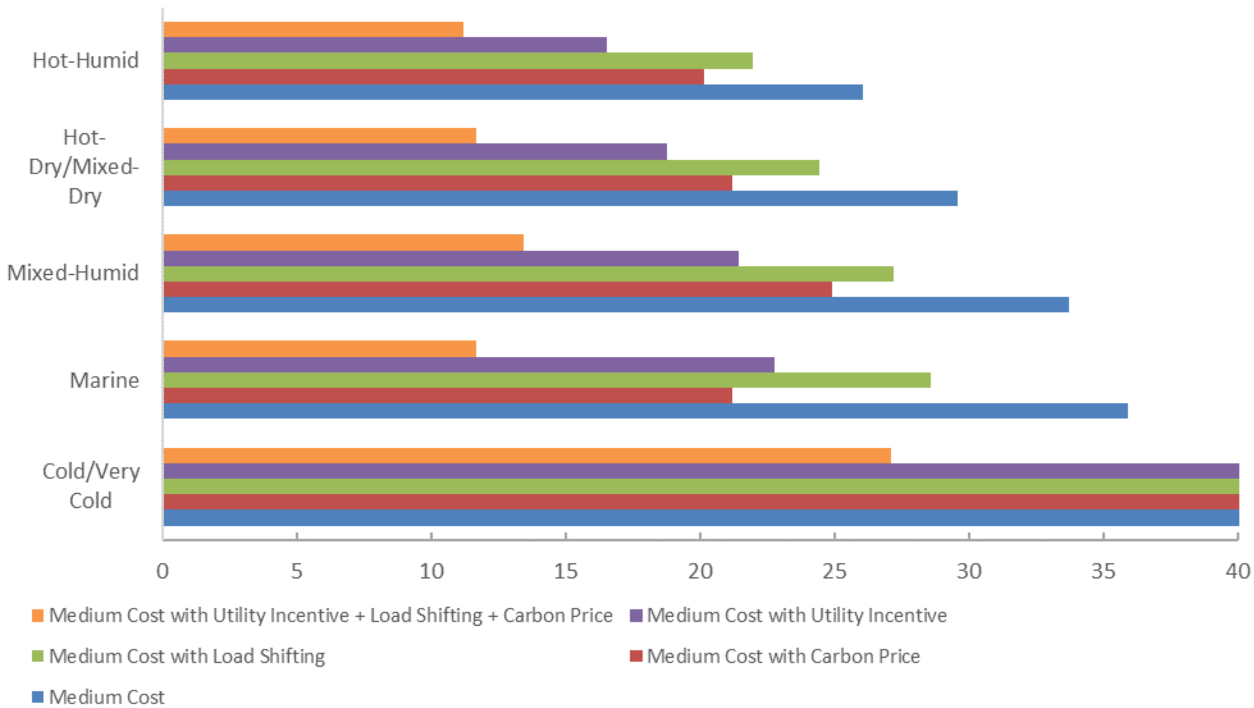

Figure B-3. Average simple payback by region from installing an in-unit heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced under different sensitivity scenarios

CENTRAL SYSTEM

Similar to our in-unit analysis, when divided into the four major U.S. quadrants, the central system analysis has at least 26 data points for each region. Figure B-4 shows the results.

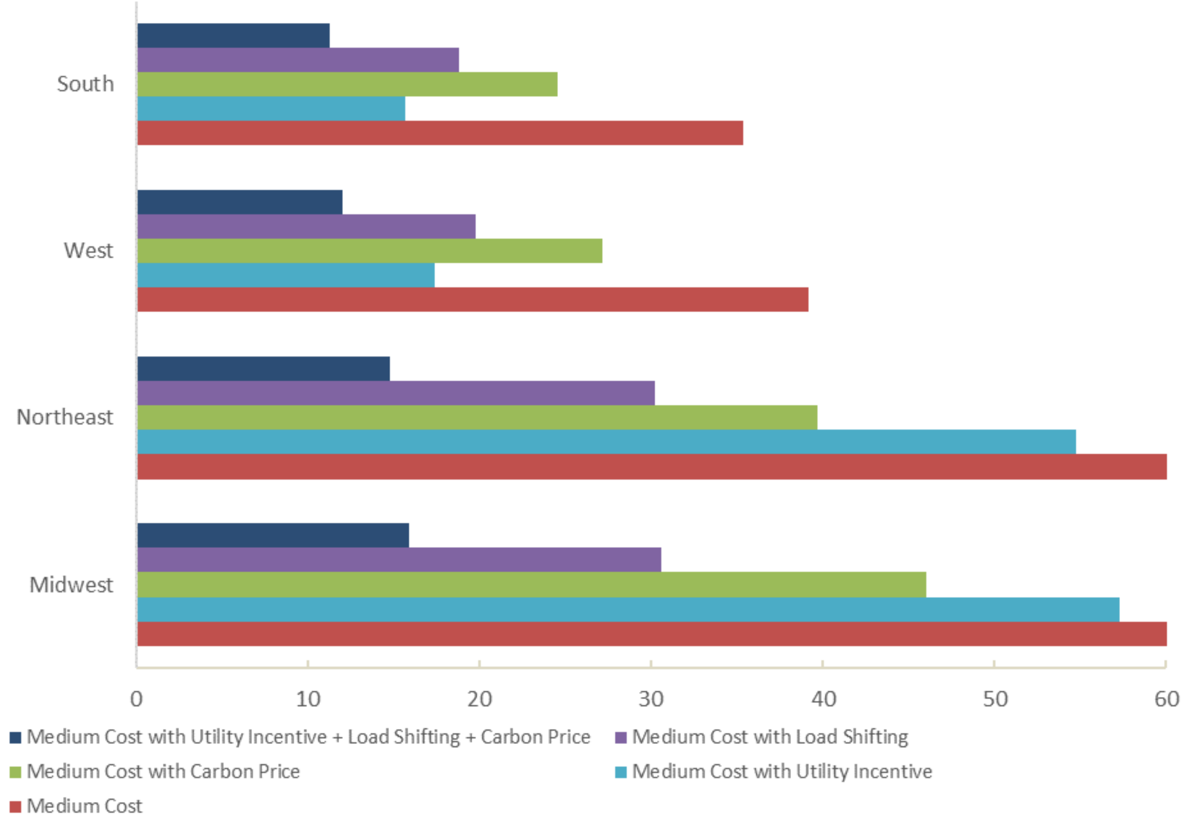

Figure B-4. Average simple payback by region from installing a central system heat pump water heater (HPWH) system where an existing natural gas water heater system needs to be replaced under different sensitivity scenarios

Dividing by climate region results, unexpectedly, in more favorable economics for cold/very cold equipment than we find in the in-unit analysis. While this may be partially due to the way the electricity and natural gas prices are divided in these regions, sample size may be another factor. For example, there are 150 entries in the database for cold/very cold central systems and only 15 for mixed-humid. Figure B-5 shows the results by climate region.

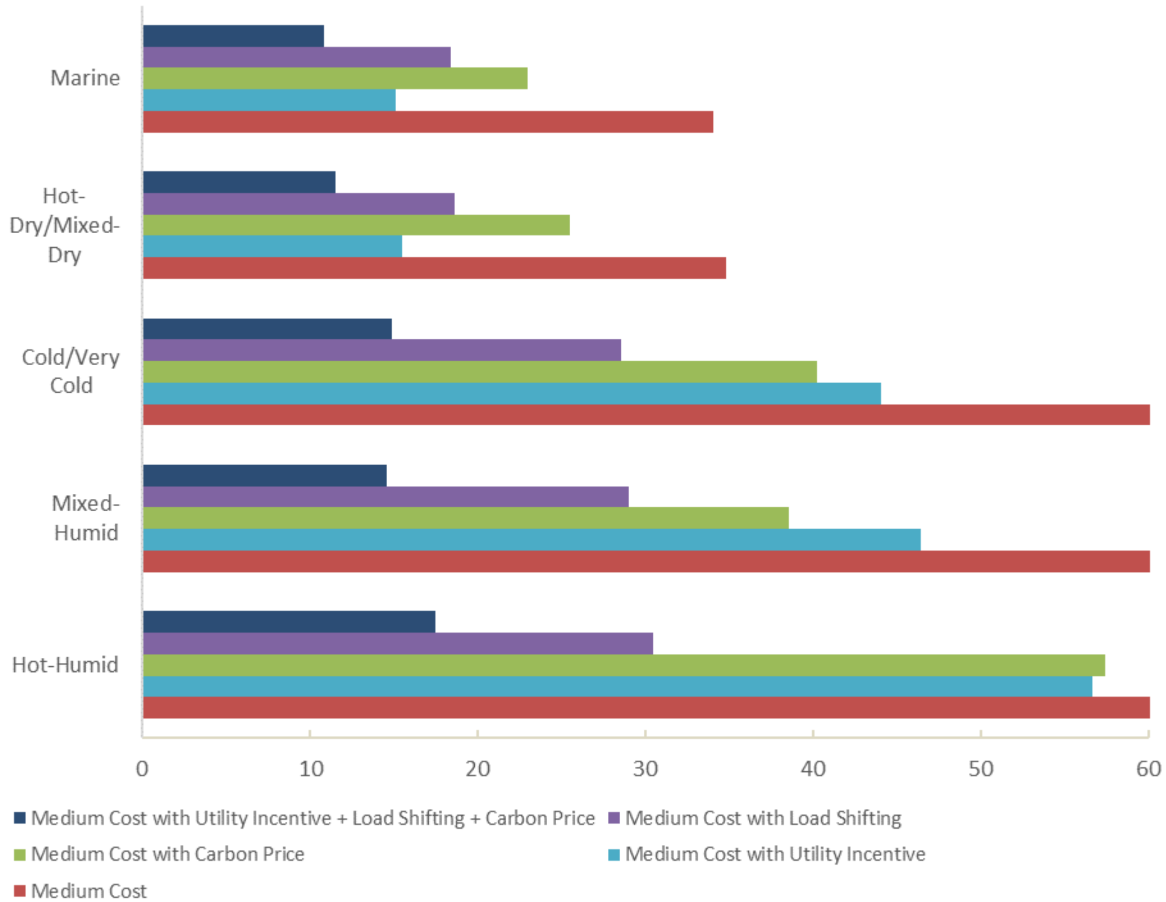

Figure B-5. Average simple payback by region from installing a central system heat pump water heater HPWH) system where an existing natural gas water heater system needs to be replaced under different sensitivity scenarios

Appendix C. Key Design Considerations

Heat pump water heaters (HPWHs) have unique design considerations, especially when retrofitting an existing gas system. This appendix identifies these considerations for both in-unit systems and central systems.

IN-UNIT

Airflow and Venting

To properly function and achieve maximum efficiency, HPWHs need room to breathe. This is because a HPWH draws heat from surrounding air (intake) and expels cold air (exhaust).

Compared to single-family homes, multifamily installations present unique challenges for unitary HPWHs. In a single-family home, HPWH installation guidelines often recommend that these systems be installed in conditioned or semi-conditioned garages, basements, or laundry rooms. Such rooms typically meet the common 750 to 1,000 cubic feet room size requirements. However, multifamily units rarely contain such rooms.

Instead, multifamily water heaters are typically placed in mechanical or utility closets, which do not provide the space needed for efficient operation.[32] To compensate, these small rooms must contain louvered doors and/or ducting to another area. However, installation guidelines typically recommend not venting the cool discharge air into living space, which can cause comfort problems (Eversource 2018). This unfortunately leaves few options in multifamily buildings. One solution that has worked in some multifamily settings (in the right climate) is to duct heat pump discharge to an enclosed hallway where heat can be harvested and cold air rejected (G. Wickes, senior product manager—emerging technologies, Northwest Energy Efficiency Alliance, pers. comm., March 30, 2021).

Because the cold air rejected from the unit may cause occupant discomfort in living areas, it might be tempting to vent the cold air outside the building. However, research shows that, on average, exhausting the air outside increases overall energy use by about 3%. Venting air to the exterior essentially depressurizes the interior space—that is, it creates a vacuum where heat is transferred outside the dwelling unit and cold outside air is sucked into the dwelling unit through gaps in the exterior walls, and thus more energy is needed to heat the space (Widder et al. 2014). In some gas-to-heat pump retrofit scenarios, it is possible to repurpose existing gas flue and fresh air makeup vents (used to exhaust gas fumes and supply "lost" air back to the space) into ductwork or passive air exchange pathways (N. Dirr, director of

[32] In a small, enclosed space, these units exhaust cold air, cooling down the space and then draw that air back into the dwelling unit. Since HPWHs operate less efficiently in colder temperatures, this may negate the unit's energy-saving abilities.

programs, Association for Energy Affordability, pers. comm., April 13, 2021). Figure C-1 shows an example of an HPWH with its exhaust vented to outside the closet.

Figure C-1. Example of a heat pump water heater (HPWH) with its exhaust ducted to outside closet to ensure sufficient airflow. Source: Widder et al. 2014.

Electrical Capacity

Another consideration for in-unit water heater installations is the available electrical capacity—the total available capacity of the main electrical service delivered to a dwelling unit from the utility, measured in amps. Apartments that do not have the required capacity may require costly modifications to the electric panel. Many newer apartment buildings include excess electrical capacity, but this typically is not the case in many older multifamily buildings. "Especially in pre-1980 apartments, electric panels at the apartment level and upstream are sized for the loads that are already in there" (N. Dirr, director of programs, Association for Energy Affordability, pers. comm., April 13, 2021). As an example, a multifamily building from 1950 may provide only 20–40 amps per apartment, whereas a new multifamily building could range from 25 to 70 amps per apartment. AEA provides a detailed overview of steps to evaluate the existing electrical system in a multifamily building for electrification upgrades; those steps include collecting electrical system data, evaluating load and capacity, and conducting calculations per the National Electrical Code (Aitchison et al. 2021).

Sound

While the heat pump is running, the water heater makes a low hum. That hum in one common unit, the Rheem Proterra, is rated at 49 decibels (Rheem 2020); for comparison, a refrigerator's hum is typically around 40-45 decibels. This sound could potentially be an issue if the water heater is located directly next to a bedroom. Soundproofing can help dampen the noise in such cases, but it adds additional cost to the installation and is not very effective with a louvered door.

Space Constraints

HPWHs are typically larger than the natural gas water heaters they replace, both in height and diameter. Mechanical closets in apartments are often designed to be as compact as possible to maximize living space, which can make some retrofits untenable.

CENTRAL SYSTEM

Central systems require several design considerations; some overlap with in-unit systems, while others are unique.

Sizing

One of the most common misconceptions in the industry is that a heat pump system replacing a central boiler or water heater system has relatively similar capacity. These systems operate very differently, however, and the installation design must account for these differences. A natural gas boiler system is designed to remain off until it is needed, and it then ignites a flame for a brief but intense period of time to heat the water. In contrast, a heat pump system is designed so that the compressor runs 12–16 hours per day. This means that, from a capacity perspective, heat pump systems can be substantially downsized in comparison to a natural gas system.[33] However, the storage requirement is increased for HPHWs because they heat water at a slower rate than natural gas systems. It is thus important to consider the additional space required for storage tanks in the design of a heat pump system, especially since the size of boiler rooms has steadily decreased over the years.

Airflow and Venting

As with in-unit systems, central systems must be installed in such a way that they can intake and exhaust sufficient airflow. A key feature of these units is that they absorb the heat from the surrounding air and store it in the tank. However, the side effect is that they cool the surrounding air. They also exhaust cold air, which further cools the surrounding space. Steven Winter Associates has observed applications in which designers used packaged units in small mechanical rooms, and the units absorbed so much heat from the surrounding air that the designers had to add space heaters to compensate, which essentially negated the energy efficiency benefits of the HPWH (N. Ceci, principal mechanical engineer, Steven Winter Associates, pers. comm., March 4, 2021).

Most multifamily central system applications will require a split system, and the placement of the compressor can have a large impact on the overall system performance. In some

[33] In Bonneville Power Administration’s territory, the most common design mistake for central systems is oversizing the system capacity and undersizing the storage (K. McVey, program manager, Energy Efficiency Emerging Technologies, Bonneville Power Administration, pers. comm., March 23, 2021). This can strain the compressor, which in turn causes it to cycle and burn out.

applications and climates, the compressor can be placed outside, such as on the roof. However, this is highly dependent on the refrigerant being used, since not all refrigerants perform well in cold climates.

Sound

Similar to in-unit HPWHs, sound from central HPWH systems must be considered. Amy Nagengast, formerly of Bright Power, found that in suburban areas the noise was less of a factor. In higher density areas such as San Francisco, however, there may be issues with noise—especially if the system is on a building rooftop and an apartment building overlooks that rooftop. Nagengast notes that if an HPWH system produces 85 decibels and the code requires 55 decibels, this constitutes an installation barrier that must be considered (A. Nagengast, senior energy engineer, formerly of Bright Power, pers. comm., March 4, 2021).

Electrical Capacity

Like in-unit HPWHs, central systems may require more electrical capacity than is available in the building, which could result in costly upgrades. Another consideration for split system HPWHs that have the compressor located on the roof is cost: If the roof's existing power is insufficient, running wire from a mechanical room to the roof can be quite costly.

Refrigerant Options

Refrigerant selection is extremely important depending on the climate and the heat pump application. The most common refrigerant for central HPWH systems is R134a, used by Rheem, AO Smith, Colmac, Nyle, and AERMEC. One main benefit of this refrigerant is that it is relatively inexpensive. However, its primary drawback is that it operates poorly in cold temperatures (i.e., around 40 degrees and below) (Grist 2021). Another refrigerant growing in popularity for central HPWH systems is CO_2 (R-744), which does not lose nearly as much efficiency in cold temperatures and can operate down to temperatures of –15˚F to –20˚F. However, CO_2 is available in fewer units (SanCO_2, Mitsubishi, and Lync/Watts currently use it) and is a more expensive compared to other refrigerants.[34]

One of the most important environmental aspects of refrigerants is their global warming potential (GWP).[35] This is where CO_2 has a major advantage: 1 kilogram of R134a is roughly equivalent to 1,430 kg of CO_2. Other refrigerants with low GWP—such as R152a, R1234yf, propane (R290), and ammonia (R-717)—may become more prevalent in water heaters over time. These refrigerants have been tested in R&D projects and are used in applications in

[34] While the cost of the refrigerant is relatively low, the associated components are typically higher than for non-CO_2 systems.

[35] Global warming potential (GWP) measures how much energy the emissions of 1 ton of a gas will absorb over a given time period relative to the emissions of 1 ton of carbon dioxide (CO_2).

countries outside the United States. Some U.S. manufacturers have confirmed their intent to commit to an alternative refrigerant (for example, Nyle has announced that it is redesigning its central HPWH to use R513a blend refrigerant). However, there are seemingly always tradeoffs with refrigerants. For instance, a refrigerant such as propane is natural and has a very low GWP; however, it is also extremely flammable (Kleefkens 2019). Table C-1 shows the GWP of common and emerging refrigerants.

Table C-1. Global warming potential for common and emerging HPWH refrigerants

Refrigerant	Global warming potential (GWP)
Ammonia (R-717)	0
CO_2 (R-744)	1
Propane (R290)	3
R-123yf	4
R-152a	124
R-134a	1,430
R-410a	2,088

Source: Oram 2029

Single Pass versus Multi-Pass

Closely tied to refrigerant choice is the primary system design type: single pass or multi-pass. Each system type has its own advantages, disadvantages, and best applications. Although the use of single-pass or multi-pass systems should (ideally) not affect the user experience, it is a tremendously important consideration for system designers and installers. Generally, the main differences between the systems are in how fast they heat water and in their incoming water temperature limitations. In addition, CO_2 refrigerant can be used only in single-pass systems, while other (non-CO_2) refrigerants can be used in both single-pass and multi-pass systems.

Single-pass HPWHs raise the water temperature all at once. For instance, the incoming water may be at 50˚F, but the heat pump system will heat it up all at once and it will produce hot water (e.g., 140˚F).[36] CO_2 refrigerant is used only in single-pass systems because efficiency

[36] However, this should not be mistaken for something like a tankless or instantaneous water heater, since a single-pass HPWH limits the gallons per minute of the water it heats, so it will still take time to heat a full tank.

drops dramatically at high water inlet temperatures. An important design consideration with single-pass systems is that they require cold incoming water temperatures (e.g., 50˚F) to perform efficiently. The majority of U.S. ground water stays reasonably temperate year-round, but designers in the hottest climates in the southern regions should assess the range of ground water temperatures to see if a single-pass system is appropriate. Warm incoming water greatly reduces the HPWH's efficiency and can damage the compressors.

Multi-pass systems heat the water more slowly in stages. If 50˚F goes into the heat pump, it may send it back to the tank at 60˚F (i.e., on the first pass); the water is then sent back to the heat pump and it produces 70˚F (i.e., on the second pass), and so on. These systems can handle warm incoming water without sacrificing efficiency. However, some multi-pass systems are unable to achieve the same high temperatures of single-pass systems (e.g., 110–120˚F rather than 140˚F) and may require some electric resistance heating to lift water to the required temperature. Multi-pass systems use refrigerants such as R134a and R410A. Figure C-2 shows single-pass and multi-pass system diagrams.

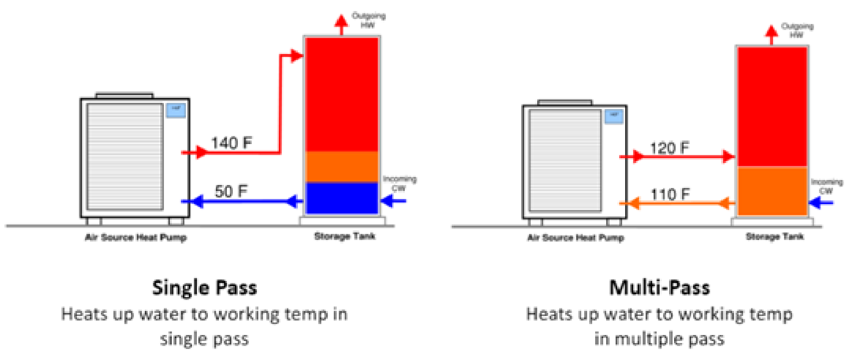

Figure C-2. Single-pass versus multi-pass commercial HPWH Systems. Source: Oram 2020.

One system design takes advantage of each of these system's strengths and weaknesses. This system design uses a single-pass CO_2 system as the primary HPWH because it uses ground water with a relatively low temperate year-round. The system then uses a multi-pass system as a secondary water heater to keep the water in the recirculation loop warm, since the incoming water from the recirculation loop is too hot for a single-pass system (M. Frankel, director of technology and innovation, Ecotope, pers. comm., May 6, 2021). However, for retrofit applications, space and/or electrical capacity may be insufficient for both primary and temperature-maintenance systems. In such cases, using a multi-pass system as the sole system can be a compromise option (N. Dirr, director of programs, Association for Energy Affordability, pers. comm., August 23, 2021).