Room Heat Pumps Market Transformation Initiative

Appendix C: Product Assessment Report

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Contents

List of Abbreviations

Abbreviation	Definition
AC	Air-Conditioning
ACC	Avoided Cost Calculator
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CA	California
CARB	California Air Resources Board
CARES	California Alternative Rates for Energy
CalMTA	California Market Transformation Administrator
CCR	California Code of Regulations
CEC	California Energy Commission
CEER	Combined Energy Efficiency Ratio
CFR	Code of Federal Regulations
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
DOE	Department of Energy
DR	Demand Response
EPA	Environmental Protection Agency
ESJ	Environmental and Social Justice
EUI	Energy Use Intensity
GHG	Greenhouse Gas
GWP	Global Warming Potential
HEER	Heating Energy Efficiency Rating
HEPA	High Efficiency Particulate Air
HFC	Hydrofluorocarbon
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IOU	Investor-Owned Utility
IPCC	Intergovernmental Panel on Climate Change
MERV	Minimum Efficiency Reporting Value
MF	Multifamily
MTI	Market Transformation Initiative
NREL	National Renewable Energy Laboratory
NYCHA	New York City Housing Authority
PG&E	Pacific Gas and Electric
PHP	Portable Heat Pump
RACC	Refrigerant Avoided Cost Calculator
RHP	Room Heat Pump
SACC	Seasonally Adjusted Cooling Capacity
SCE	Southern California Edison

SDG&E	San Diego Gas and Electric
SF	Single-Family
SMUD	Sacramento Municipal Utility District
TOU	Time of Use
UES	Unit Energy Savings
WAC	Window Air Conditioner
WHP	Window Heat Pump

1 Executive Summary

1.1 Document purpose and scope

This Product Assessment Report discusses the key findings of CalMTA's product and technical research into room heat pumps (RHPs), including product features, limitations, and technical considerations for their use in California. The main product assessment activities informing this report were a review of existing literature, review of available products, discussions with manufacturers, and energy modeling. Those activities and this report will inform a forthcoming Market Transformation Initiative (MTI) Plan. The full MTI Plan will include a more comprehensive explanation of the benefits of the initiative for Californians and a complete program logic for transforming the RHP market.

RHPs provide an efficient solution to electrified space conditioning in multifamily and smaller single-family homes in California where complex equipment installations are not practical or desired. While the cooling efficiency of new RHPs is expected to be comparable to that of new room air conditioners, they can replace less efficient heating sources such as electric resistance or gas furnaces, providing significant benefits to the electrical grid and greenhouse gas (GHG) emissions. Here, we review the currently available products, applicable codes and regulations, as well as product gaps related to the needs of the California market. We then use energy modeling to estimate the potential of energy savings, avoided cost benefits, and bill impacts for both single- and multifamily buildings across all of California's climate zones. This information will then be used to inform how the MTI Plan addresses barriers, interventions, and outcomes.

The Product Assessment Report covers RHPs that provide space conditioning in single zones up to 1000 ft^2. These devices are small heating, ventilation, and air-conditioning (HVAC) appliances that plug directly into a typical 120V electrical outlet and can provide efficient heating and cooling to one area in a home. Different form factors of these products can sit within a window opening, in a sleeve through a wall, or on the floor near a window with intake and exhaust hoses for the heat pump to operate. The form factors and operation of these devices are similar to window air conditioners and portable air conditioners, except that they can also work in reverse, to provide highly efficient heating, about three times more efficient than electrical space heaters or baseboard units.

The document is organized by first providing an overview of RHPs, their limitations, and possible technical barriers. Then it surveys the competitive landscape and current codes and standards. Following this review, it uses energy modeling to examine product performance, bill impacts, avoided costs, technical potential, and product plan actions. The report closes with a risk assessment of possible threats to the product plan. The following Executive Summary provides an overview of the report's main findings.

1.2 A note on product naming conventions

This MTI is titled "Room Heat Pumps" (updated from "Portable/Window Heat Pumps") because it focuses on products within this federal appliance category (Room Air Conditioners with Reverse Cycle). The MTI includes window and through-the-wall heat pumps and all the form factors within this category.[1] However, our MTI also includes portable heat pumps (PHPs), which are listed under the federal appliance category of Portable Air Conditioners. While the MTI prioritizes window heat pumps (WHP), CalMTA recognizes that the needs of certain consumers and building types will be better met with either PHPs or through-the-wall heat pumps. In this report, when we use the term RHPs, we refer to the collection of MTI products, including portables. This shortened nomenclature choice is meant for easier readability. For any discussion specific to a single product type, we use the name of that particular product (i.e., WHP or PHP).

1.3 Main product assessment findings

Finding 1: The newest generation of Type 4 saddlebag window heat pumps represent a huge advancement in heating performance and efficiency.

Until recently, most RHP products on the market did not provide sufficient heating capabilities to serve as a sole source of heating for a living space, even in California's relatively mild winters. These heat pumps fell within the Environmental Protection Agency (EPA) ENERGY STAR® Type 1 category, which means they did not have active defrost and were not able to operate in heat pump mode below approximately 40°F. Several cold climate (or "Type 4" as we will refer to them) RHPs are now being released commercially in response to the New York City Housing Authority (NYCHA) Clean Heat For All Challenge.[2] These products represent an impressive leap forward in performance, capable of heating below 0°F and keeping full heating capacity down to 17°F. They are efficient at both heating and cooling, with a Combined Energy Efficiency Ratio (CEER) greater than 16, and a COP (Coefficient of Performance) for heating of greater than 2.3 at 17°F.[3] These

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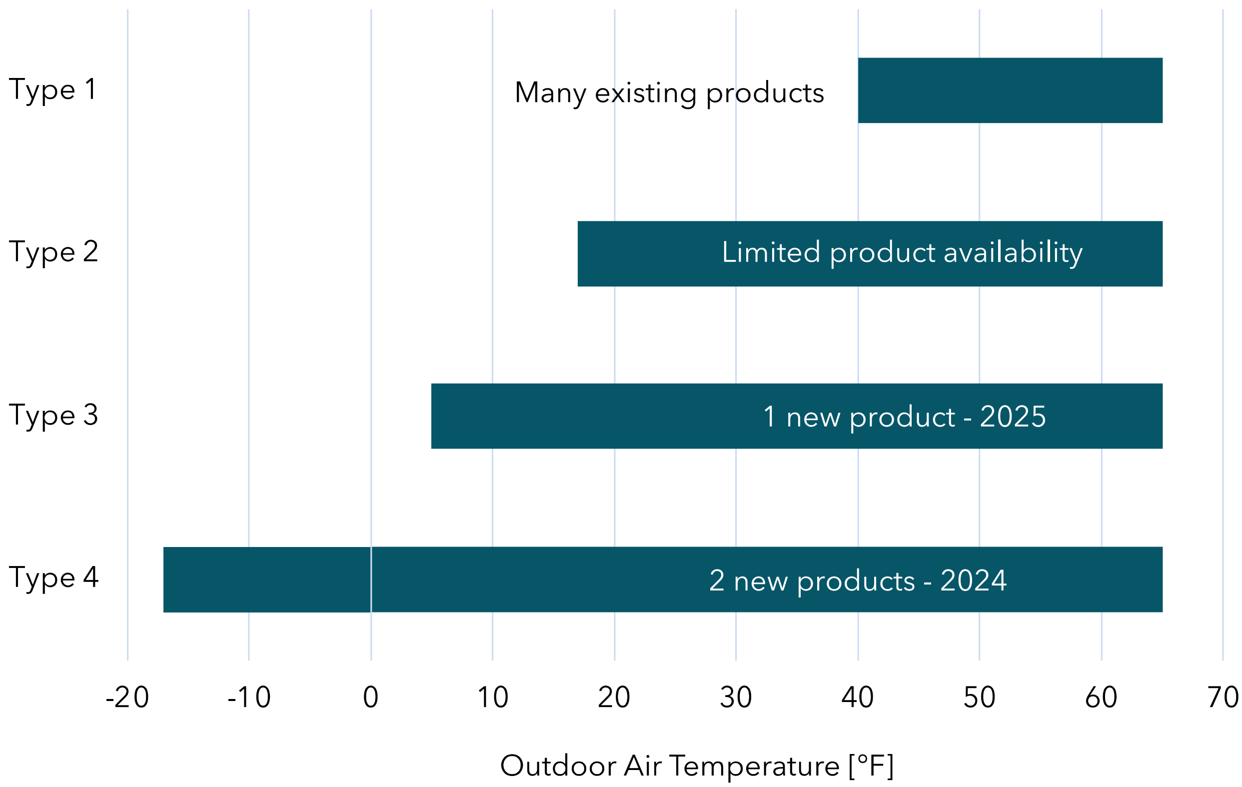
[1] As noted in Section 2, we refer to form factors as the different basic geometries of these small heat pumps, namely: portable, saddlebag, U-shaped, and traditional window AC (cube). See Figure 5 for a picture of each type.

[2] https://nychanow.nyc/70-million-initial-investment-will-decarbonize-nycha-buildings-with-new-heat-pump-electrification-technologies/.

[3] This far exceeds the current federal efficiency standards for RHPs with reverse cycle CEER 10.4 and even exceeds the 2026 level of 14.4. They meet the minimum efficiency requirement for room air conditioner without reverse cycle (CEER = 16), which is 10% higher than for Room Air Conditioners with Reverse Cycle (i.e., room heat pumps).

products use a saddlebag shape that keeps the compressor isolated outdoors for quiet operation and also allows the window to open and close while the unit stays in place.

Figure 1. Operating temperature for EPA ENERGY STAR room heat pump designations



These Type 4 heat pumps also demonstrate that it's possible to create RHPs that can match the performance of ductless mini-splits without a complicated and expensive installation. Moreover, they improve on the lackluster aesthetic appeal of traditional window air conditioners. Currently the cost of these high-performance RHPs is a challenge for low-income consumers.[4] This MTI, however, will work with existing manufacturers and incentivize new market entrants to balance costs with the right performance needed for California winters.

Finding 2: Portable Heat Pumps are less efficient and less capable of heating compared to window heat pumps.

PHPs are in a separate federal appliance category than WHPs and are freestanding self-contained heat pumps that have one or two hoses that attach to a window to transfer heat with the outdoor

[4] In September 2024, a major manufacturer announced a new room heat pump and preliminary information indicates that this may fall within the Type 2 or 3 product category. Specific performance and pricing information was not available at the time of publication.

air.[5] They are typically on rollers so they can move from room to room. These units are prone to transferring unwanted heat to/from the outdoors through the hoses, and single hose units have the additional efficiency detriment of drawing in unconditioned outdoor air during operation. The compressors on these products are located within the living space creating more noise than products with the compressors outside, and they require a condensate drain tube for accumulated water. Like most older WHPs, all PHPs currently on the market do not contain active defrost and cannot heat below 40°F – unless the product includes inefficient backup resistance heat. Lastly, the size of the heat exchanger and therefore the efficiency of the heat pump is limited because the entire unit is within the living space. Portable and RHPs are in different appliance categories and thus do not use the same test procedure to quantify cooling efficiency; the new EPA ENERGY STAR test procedure for heating efficiency currently only applies to RHPs.[6] Our energy modeling estimates that PHPs will use 43% more HVAC energy in multifamily dwellings in California compared with RHPs. This estimate is likely conservative because we do not account for additional air infiltration that may occur with PHPs.[7]

Finding 3: New plug-in heat pump products are needed to meet the climate and window styles of California.

Today's window heat pumps require a single or double-hung window, which is an operable window that can slide up to allow the heat pump to straddle the windowsill. A CalMTA consumer survey found that less than half of California residents surveyed had single- or double-hung windows capable of accommodating a WHP.[8] This finding was also confirmed anecdotally from the RHP installation pilot where many of the prospective multifamily buildings did not have the correct type of operable windows. A CalMTA consumer survey found the majority of respondents have either slider or casement operable windows, which have a much narrower opening.[9] The only type of product currently on the market that would work with these window types is the PHP, which can easily accommodate a wide variety of opening geometries through adapter kits that place the hoses within the window opening. As mentioned in the previous finding, the PHPs currently on the market have relatively low efficiency and poor low temperature heating performance. They are not ideal products for the primary source of space heating or air conditioning for living areas. Despite the performance drawbacks, they are the only plug-in heat pump option for a large portion of Californians, and PHPS will still save energy compared to electrical resistance heating. These findings highlight a future product need for a high-performance heat pump that can work with narrow window openings of approximately 15" wide.

[5] As described above, PHPs are in the Portable Air Conditioner appliance category and RHPs are known as Room Air Conditioners with Reverse Cycle by federal appliance categories.

[6] Both appliance categories use CEER for cooling efficiency, but despite using the same name the metric is different for each appliance and not directly comparable.

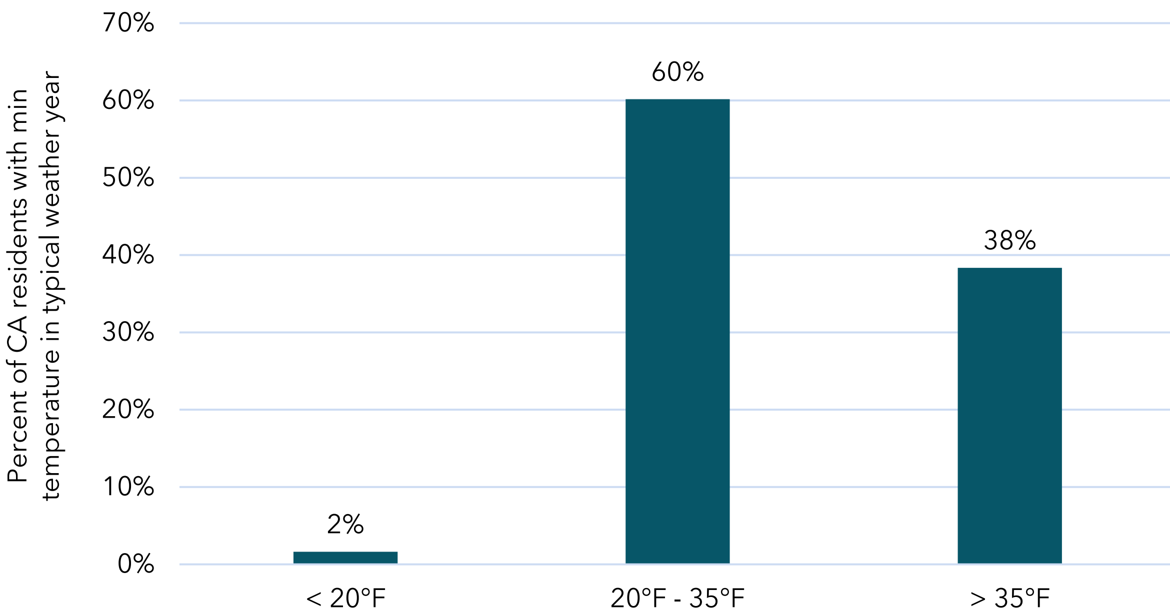
[7] Our modeling considers dual hose PHPs which do not generate negative indoor air pressure like single hose PHPs.

[8] See Appendix D: Market Characterization Report for Room Heat Pumps.

[9] CalMTA market survey found 55% of respondents had only casement or slider windows.

As noted in Figure 1, there are currently new Type 4 RHP products with minimum operating temperatures below 5°F and a number of existing products with a minimum operating temperature greater than 32°F. No commercially available RHPs in the US currently meet the minimum operating temperatures of 5°F to 32°F,[10] which is the range of required minimum heating temperatures for most California homes during typical winters.[11] RHPs optimized for cold climate operation (i.e., Type 4 heat pumps) can often have increased costs due to the compressor and heat exchanger requirements needed to perform at temperatures below 5°F. A product optimized for heating down to 25°F instead of -5°F may have a reduced weight and cost, increasing its attractiveness, especially for budget-constrained consumers. Figure 2 shows population bins based on lowest temperature in a typical weather year. These bins correspond with the ENERGY STAR RHP designations and indicate that 60% of California residents would need a Type 3 RHP, 38% would need a Type 2, and only 2% need a Type 4 heat pump.[12]

Figure 2. Percent of California residents with specified minimum temperature in typical weather year



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[10] Based upon manufacturer and stakeholder interviews as well as web searches, as of August 2024. A new product has been announced that will fall into Type 3 and be available for purchase in the beginning of 2025.

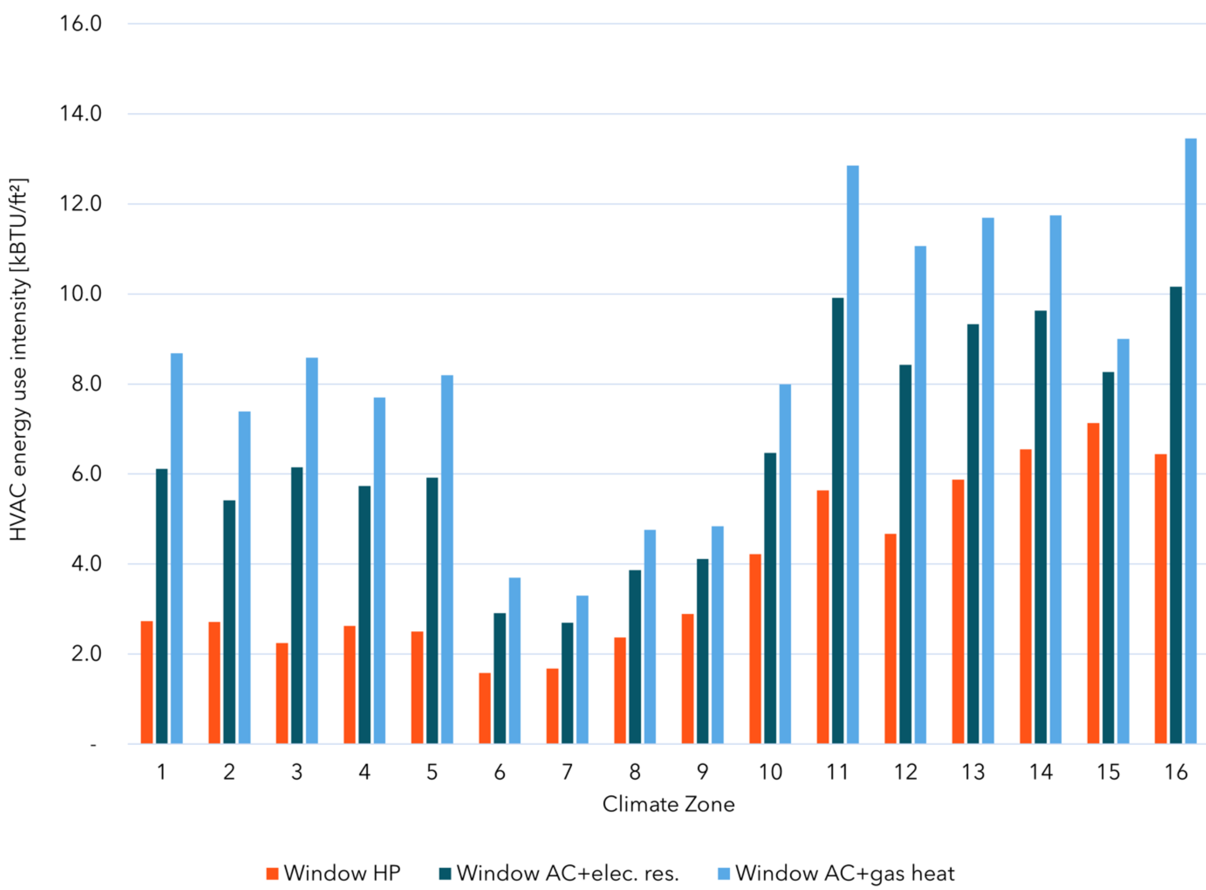
[11] Based upon an analysis of the CALMAC 2022 typical weather years that that span 20 years of weather data from 1998 through 2017 and were adopted for CA Title 24 Version 2022. https://www.calmac.org/weather.asp.

[12] In this analysis, we use typical weather rather than design days since these products are not often the sole source of heating, we find this a more instructive metric. In the next phase, we will continue to explore user behavior and install cases to better understand the potential of these products to serve as the only HVAC equipment for a dwelling.

Finding 4: Choosing room heat pumps over electric resistance or gas wall furnaces creates a significant potential for energy savings.

CalMTA energy modeling work demonstrated significant potential for energy savings and reduction of GHG emissions by replacing less efficient heating technologies, such as electrical resistance baseboards or gas wall furnaces, with RHPs. For the new Type 4 heat pumps, we estimate an average HVAC energy savings of 42% over a window AC + electric baseboards or 54% over a window AC + zonal gas heat for a multifamily (Figure 3). Both changing from other forms of electric heat or from gas results in a significant avoided cost benefit through a reduction of energy consumption and GHG emissions. In our scenarios, we assume equally efficient cooling by an RHP or room air conditioner. The energy savings come from the heating. Significant energy savings can be achieved in all 16 climate zones, and the savings are even higher in small single-family buildings where the total heating and cooling loads are higher.

Figure 3. Annual HVAC energy consumption by climate zone in multifamily building for three scenarios: 1) Window heat pump 2) Window air conditioner + electric resistance heat 3) Window air conditioner + zonal gas heat



Finding 5: Changing from electric resistance heat may potentially result in large consumer utility bill savings, but the impacts when substituting electric from gas heat may vary under current rate structures.

Consumers moving from electrical resistance heat will see utility bill savings across all 16 California climate zones, with an annual average savings of $163 for a multifamily home using a WHP.[13] The annual savings using a PHP is $95. Consumers moving from gas to an electric heat pump, will likely see a bill increase despite energy savings, although in many regions the increase is relatively small.[14] The average annual increase for changing from zonal gas heat is $14 for a WHP and $82 for a PHP. We anticipate significant variability in the bill impacts for individual consumers, which will depend on the building characteristics, weather, thermostat setpoint, heat pump performance, existing space conditioning type, and utility rate structure. Certain municipal rates, however, will see bill savings even when fuel substituting. Equipping consumers with accurate bill estimates will be helpful in minimizing negative financial impacts within environmental and social justice (ESJ) communities and allow them to make informed buying decisions.

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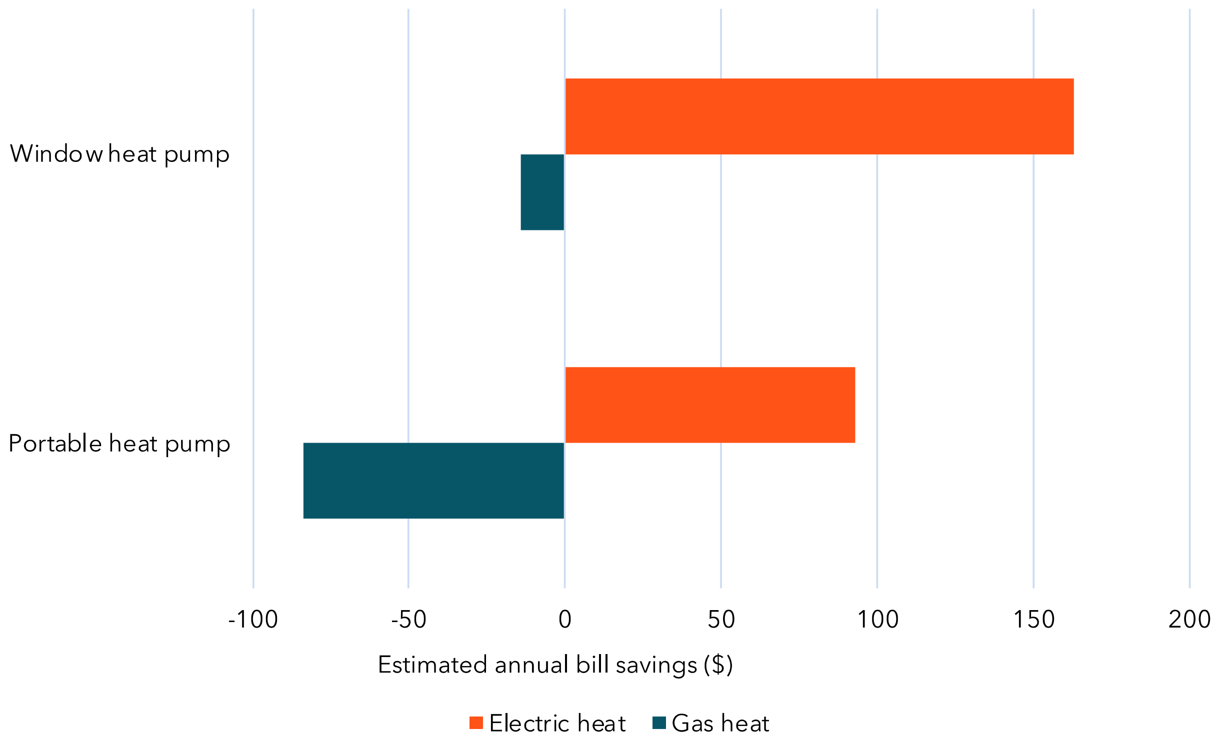
[13] Annual savings from an average of three IOU time of use rates across all 16 climate zones for a 1,024 ft^2 multifamily apartment switching from electrical resistance heat to a high efficiency Type 4 room heat pump.

[14] Because gas is much cheaper than electricity per unit of energy, these electric heat pumps can sometimes save energy but be more expensive to operate. This is discussed in the Bill Impacts section in more detail.

Figure 4. Estimated annual bill savings when changing to room heat pumps from existing heating technologies using investor-owned utility (IOU) rates



Finding 6: Future product needs include heat pumps optimized for the California climate, options with air filtration and ventilation, and lower global warming potential refrigerants. Early in its development, this MTI identified the importance of air filtration to provide improved indoor air quality (IAQ) to occupants, especially those in ESJ communities. RHP products available today do not provide air filtration, which is a future product need for the California market. Adding high-efficiency air filtration to an RHP may increase operating expenses by reducing energy efficiency and adding the cost of replacement filters. This should be considered when working with manufacturers on new product offerings. Including mechanical ventilation as an option on some RHPs can also improve IAQ through the introduction of outdoor air into the living space. Incorporating mechanical ventilation can also reduce energy consumption in climates that can benefit from nighttime cooling. Another future product need is reduced global warming potential (GWP) refrigerants. Currently, we find the most common RHP refrigerant, R32, would contribute approximately 20% to the lifetime GHG emissions of the heat pump if emitted into the atmosphere.[15] Switching to a natural refrigerant, such as propane, would reduce the refrigerant GHG contribution to less than 1%. The flammability of propane, however, creates significant safety barriers and existing codes must be addressed with further research and product development.

[15] Assuming the entire charge of refrigerant is emitted and using the 20-year GWP value.

2 Product Overview

2.1 Background on room heat pumps

While different types of air-source heat pumps have been commercially available for more than 50 years, RHPs are a more recent entry into the category. Many inexpensive products exist to provide zonal heating, including electric baseboards, electric space heaters, and gas wall furnaces, to name a few. With rising energy prices and improved product development, compact heat pumps have entered the market as an energy-efficient solution to space heating. The basic components have existed in room air conditioners for decades, and the initial entrants were virtually indistinguishable from their cooling-only counterparts. As the market advances, high-performance RHPs diverge from room air conditioners in size and form due to the extra challenge of providing heating at very low temperatures (< 5°F) and incorporating active defrost control for the outdoor coils. These newer, high-performance Type 4 RHPs are now poised to enter the market. They offer the possibility of using portable plug-in devices to provide highly efficient space conditioning to small living areas. In this product assessment, we discuss the advantages and disadvantages of RHPs compared with competing technologies and identify key needs to increase market adoption of these products.

2.2 Product definition

RHPs are self-contained consumer products that provide efficient heating and cooling for small spaces ranging from a single room, a modest apartment, or small home. They are similar in shape and size to traditional window AC units and portable AC products. The product type targeted by this MTI uses variable speed operation providing more efficient cooling in the summer and heating in the winter. Variable speed operation allows RHPs to operate efficiently even when the outdoor conditions are relatively mild compared to the design temperature and capacity of the unit. These products can be installed without a certified electrician or HVAC technician and plugged into a 120-volt outlet. CalMTA is targeting products with a cooling and heating capacity range of approximately 8,000 to 14,000 BTU/h, which are designed to condition approximately 400 to 1,000 ft^2, due to the relatively mild California winter climate. This MTI targets both single- and multifamily dwellings, to provide a primary source of space conditioning in smaller dwellings and perhaps to displace central space conditioning in larger dwellings. The heating capacity of these compact heat pumps can be highly temperature dependent, however, and many current models cannot provide the same level of heating at or below 40°F.

The MTI products fall into two different categories according to federal appliance standards, both of which only have efficiency standards for the cooling cycle (portable AC starting in 2025) and not for heating. PHPs (Figure 5a) fall under the category of Portable Air Conditioners, which describes moveable products that sit on the floor and connect to outdoor air via one or two ducts running to a window, and the federal efficiency standards for this appliance take effect in 2025. Window and through-the-wall heat pumps fall under the category of Room Air Conditioners with

Reverse Cycle. In this category, three additional different form factors are included: U-shape (Figure 5b), saddlebag (Figure 5c), and traditional box window units (Figure 5d).[16] These products can be self-installed with their outdoor and indoor components straddling the window sash. Many homes in California have either casement or sliding windows, which require the use of PHPs with hoses due to the form factor constraints of window units.

Figure 5. The types of heat pumps and form factors included in this MTI: a) Dual duct portable heat pump b) Saddlebag window heat pump c) U-shaped window heat pump d) Traditional window heat pump in the same shape as a traditional window AC unit

[16] Through the wall units have the same form factor as the box window units.

Consistent with California Air Resource Board (CARB) regulations, all products must utilize refrigerants with a GWP below 750 and not include any back-up resistance heating. Cooling efficiency is set through the CEER, which is the same term for room and portable AC product categories, even though the values are calculated differently based upon a different test procedure and thus difficult to compare. RHPs in this MTI will align to the 2026 federal efficiency standard where the CEER must be greater than 14.4. The CEER requirements for portable versions vary with capacity, but for a 10,000 BTU/h unit, a CEER of 7.8 is required. WHPs have higher efficiency and are prioritized as the preferrable product except in cases where window configuration or lease agreements prevent their use. Future requirements on heating efficiency can be set through the Heating Energy Efficiency Ratio (HEER) once ENERGY STAR sets levels in late 2024 or early 2025.

2.3 Product features

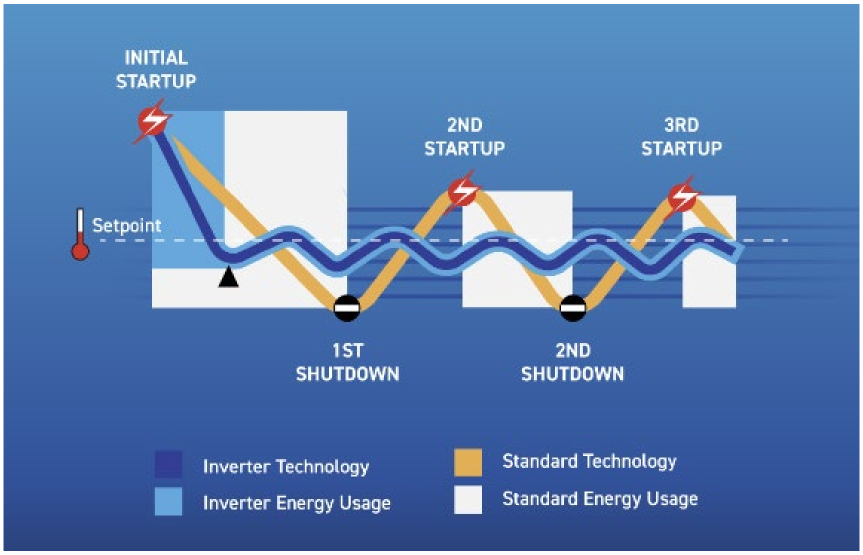
Form factor

As described in the product definition there are four form factors considered in our products: 1) dual duct PHP, 2) saddlebag WHP, 3) U-shaped WHP, and 4) traditional WHP (which also includes through the wall units). Saddlebag and U-shaped products are relatively new and add additional benefits: both are significantly quieter compared to traditional window units since the compressor and outdoor fan are separated from the interior by either the window (U-shape) or wall below the window (saddlebag). The saddlebag has the additional benefit that it does not block the window view, and both form factors typically will allow the hung window to be operated while the heat pump is installed. Through-the-wall heat pumps are a sub-category of RHPs that are included in the MTI and typically have the same form factor as a typical WHP or AC. These products slide into sleeves that are openings in the building envelope to contact both indoor and outdoor air without the use of the window.

Variable speed operation

Inverter-driven variable-capacity heat pumps can have a significant efficiency benefit, but this feature can also improve user experience through reduced noise and smaller temperature swings. By conditioning for longer periods at lower capacity, the compressor and fan noise can be reduced, allowing for finer control of the room temperature. A single-speed compressor only has two states: 100% on or 100% off. A variable speed compressor will have many different operating points and heat or cool at a lower capacity level (i.e., 50%) and run for longer to achieve the same level of heating or cooling. Inverter-driven systems include a microprocessor that enables fine control of the compressor speed and heating/cooling output to adjust to the needed conditions. This will result in fewer on/off cycles which can lead to better temperature/humidity control, lower energy consumption, as well as increase the overall life of the compressor. Figure 6 below illustrates the cycling characteristics of inverter and single-speed technologies relative to the system setpoint.

Figure 6. Visualization of the temperature and energy benefits of inverter-based variable speed operation compared to standard non-variable technology[17]



Low temperature heating performance

Most small heat pump products on the market today are designed for mild climates; they do not have active defrost capabilities, and the compressor cutoff is around 40°F.[18] The NYCHA Clean Heat for All Challenge aimed to change this with a cold climate specification for WHPs to allow efficient all-season heat pump operation in New York City. In response, Midea and Gradient created Type 4 saddlebag heat pumps designed to provide year-round heating and cooling to multifamily public housing in New York City. The manufacturer specifications for these products are shown in Table 1. These products represent a leap forward in heating performance for small heat pumps with full heating capacity at 17°F, heat pump operation below -5°F, and a COP > 2 at 17°F. They are significantly bigger than many traditional mild climate RHPs, however, as the extreme low temperature performance requires a larger heat exchanger and compressor as well as active defrost control (discussed in the next section). For comparison, an existing Midea WHP, model MAW12HV1CWT, capable of 12,000 BTU/h cooling (its heating capacity is not published), has a product weight of 58 lb. and a minimum operating temperature of 41°F.[19] In contrast, the Midea Packaged Window Heat Pump, capable of 9,000 BTU/h heating and cooling, has a product weight of 120 lb. and a minimum operating temperature of -13°F. Given the mild temperatures for winter in most of California, this product's low-temperature performance exceeds what is needed for many California consumers. Gradient recently reported the HEER from the new

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[17] https://www.friedrich.com/breeze.

[18] Compressor cutoff refers to the point in which the heat pump controls command the internal compressor to turn off and thus stop heat pump operation. For units without backup resistance heat, this is the outdoor air temperature at which the product will stop providing heating.

[19] https://www.midea.com/us/air-conditioners/window-air-conditioners/12000BTU-SmartInverter-AirConditionerWindowUnit-MAW12HV1CWT.

ENERGY STAR test procedure (discussed in the Codes & Standards section). Without comparison of other RHPs, it is not possible to directly compare this efficiency to comparable products, however with a reported COP of 4.04 at 47°F and 2.06 at 5°F, the HEER value of 9.4 is likely to represent a highly efficient RHP.

Table 1. New Type 4 window heat pumps, manufacturer specifications

Metric	Units	Midea[20]	Gradient[21]
Cooling capacity	BTU/h	9,000	9,300
Cooling efficiency	CEER	16.3	16.8
Heating capacity	BTU/h	9,000	9,000
Heating efficiency	HEER		9.4
Outdoor operating temperature	°F	-13 to 113	-13 to 115
Heating efficiency	COP @ 17°F		2.37
Refrigerant		R32	R32
Capacity at 5°F	% of Cap(47°F)	100%	80%
Form factor		Saddlebag	Saddlebag
Weight	lb.	129	140

Active defrost control

Most small heat pump products on the market today are designed for mild climate; they do not have active defrost capabilities and the compressor cutoff is around 40°F. Some products of this type will have back up resistance heat for lower temperatures while others will no longer provide heating. In either case, the mild climate heat pumps will not provide highly efficient electrical heating at lower temperatures. A significant factor that drives this cutoff around 40°F is the need for active defrost management at lower temperatures. In heating mode, a heat pump absorbs thermal energy from the outdoor surroundings which lowers the outdoor coil temperatures below ambient. Depending upon the outdoor humidity levels, this can cause moisture in the air to condense on the coils and then freeze. This layer of ice will interfere with air flow and heat transfer, decreasing the performance of the heat pump. The range of temperatures where frost can accumulate on the coils is typically between 40°F and 20°F and is most common with high outdoor relative humidity (> 65%).[22] To mitigate this issue, heat pumps operating below 40°F employ active defrost strategies to remove the ice accumulation. Common strategies to defrost are either operating the heat pump in reverse temporarily (cooling mode) or using resistance heating to the coils. In the case of reverse mode operation, the system is cooling the indoors, but

[20] Full specifications for the Midea Packaged Window Heat Pump were not available at the time of publication. The performance data published on Midea's website for HSPF2 indicates high efficiency heating, at the level of the Gradient product or better. http://www.mideacomfort.us/packaged.html, accessed December 9th, 2024.
[21] https://www.gradientcomfort.com/products/gradient-all-weather-120v-window-heat-pump.
[22] Nawaz, Kashif and Fricke, Brian, "A Critical Literature Review of Defrost Technologies for Heat Pumps and Refrigeration Systems" (2021). International Refrigeration and Air Conditioning Conference. Paper 2218.

the indoor fan will be turned off (in most cases) so that the heat pump will not blow cold air indoors. Larger residential heat pumps may have electrical resistance heaters to provide space heat during defrost. This is unlikely, however, on compact RHPs. The defrost behavior of the new RHPs should be investigated as they become commercially available.

Smart features and connectivity

Many products now include Wi-Fi or Bluetooth connectivity and provide smartphone apps for advanced control of the heat pumps. This includes basic functionality such as temperature setpoint, operation mode, as well as pre-set favorites, schedules, and more. Some apps also include diagnostics and fault detection functions. From a product performance perspective, the most important use of the device connectivity is for integration with smart thermostats and/or demand response (DR) signals. A previous Northwest Energy Efficiency Alliance field study found that in some cases portable and WHPs set to "Auto" mode were inadvertently fighting against other heating sources and swinging between heating and cooling within the same day, wasting significant energy.[23] In less extreme examples, there are many configurations in which the position of the home thermostat compared with the RHP may cause sub-optimum comfort or energy use due to the interactive effects between the central thermostat and the RHP control. Additional field data can help clarify the extent and the severity of negative interactive effects between an RHP and central HVAC system and whether an intervention will be needed to mitigate this issue.

2.4 Limitations & drawbacks of available products

Lack of window heat pump products for casement and horizontal slider windows

According to CalMTA's consumer survey, most single-family and multifamily homes have some or all windows that slide open horizontally (sliding) or outwardly (casement). A total of 75% of respondents reported having either casement or sliding windows in their home, while 55% of households had these window types exclusively. Only 42% reported having vertically hung windows in their home, while 22% of households had vertically hung windows exclusively.[24]

Typical WHPs and air conditioners are designed to fit into single- or double-hung windows that slide up vertically and have a rectangular opening at least 22-26'' wide and 14-16'' tall. For U-shaped and traditional window units, these are the only geometry requirements, while saddlebag units require additional clearance below the inside and outside of the window, typically around 24''. Clearance requirements below the windowsill can create limitations in some situations where the window is close to the floor or there are other obstructions. Saddlebag units also have a requirement on the sill depth or wall thickness, but that geometry issue is mitigated through the addition of adjustable brackets (Figure 7). The larger issue with geometry is the width requirement for all WHPs, which need a window opening approximately 2' wide. This has been

[23] https://neea.org/product-council-documents/micro-heat-pump-field-study-results-product-council.
[24] See Appendix D: Market Characterization Report for Room Heat Pumps.

identified as a significant barrier due to the team's preliminary findings that a large portion of operable windows in California are either casement or sliders. These window types have a vertically oriented rectangular opening that will not often fit the existing WHP form factors.

Figure 7. Example geometry requirements for a saddle bag window heat pump[25]

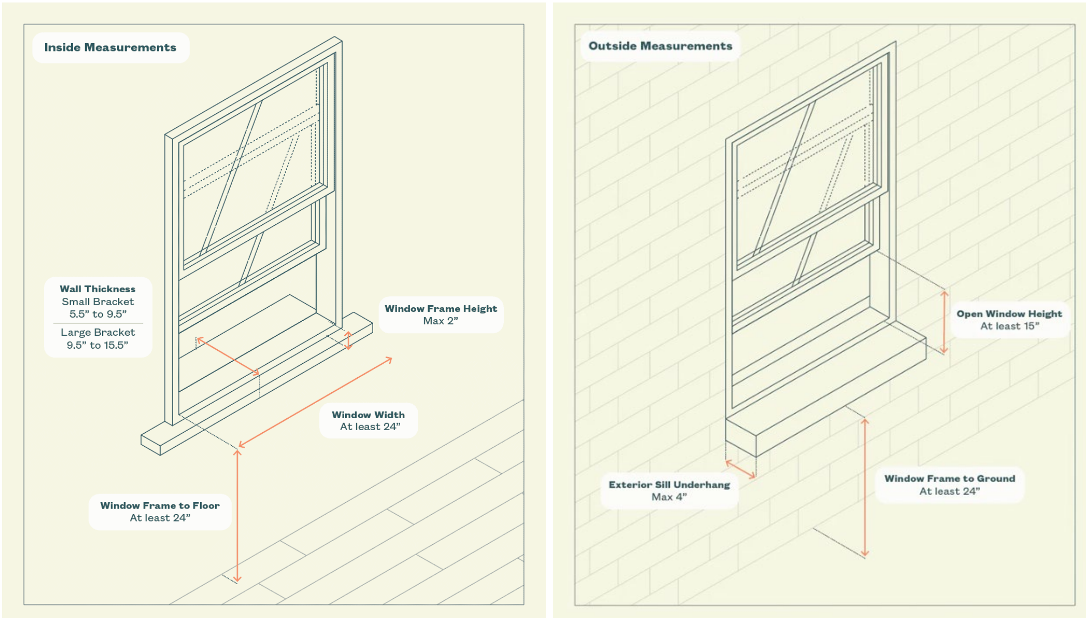


Image credit: Gradient instruction manual: https://cdn.shopify.com/s/files/1/0558/4925/5070/ files/109-00004-01_-_Gradient_Instruction_Manual_REV_4_06_06_2023.pdf?v=1686085277.

Limited options for improving indoor air quality

High-efficiency air filtration is important for the reduction of particulate matter, allergens, smoke, airborne viruses, and other small particles. While most central HVAC systems include furnace filters, there are currently limited product options for RHPs that provide air filtration. There is one major manufacturer offering the option for Minimum Efficiency Reporting Value (MERV) 13 filters, which is the filtration level required by California's Title 24, Part 6 for new multifamily buildings.[26] Friedreich offers the option to add MERV 13 filters to their Kuhl product line of air conditioners and heat pumps (Figure 8), however none of the products in this lineup includes a plug-in 120V heat pump. Adding high efficiency air filtration can negatively impact energy consumption; additionally, none of the products that include air filtration were observed to include ENERGY STAR

[25] Gradient instruction manual, https://cdn.shopify.com/s/files/1/0558/4925/5070/files/109-00004-01_-_Gradient_Instruction_Manual_REV_4_06_06_2023.pdf?v=1686085277.

[26] 2022 Title 24, Part 6 require MERV 13 filtration for all recirculated air and outdoor air, including outdoor air provided by supply air ventilation systems or the supply side of balanced ventilation systems. https://energycodeace.com/site/custom/public/reference-ace-2022/index.html#!Documents/114buildingindoorairqualityandventilationrequirements.htm.

certification. Additional investigation would be needed to understand whether this is related and the degree to which the energy efficiency would be impacted by filtration. It is important to mention that air filtration comes at an additional cost to the consumer through the cost of disposable filters. The Friedrich FreshAire filters retail for $35-$40 apiece with a recommended replacement interval of 30 days. An annual cost of $420-480, or even half that (~$220) if replaced every 60 days, for filtration media may present a barrier for some consumers. A pilot program providing PHPs and separate High Efficiency Particulate Air (HEPA) air purifiers noted the filter cost as an important operating cost to consider for low-income consumers.[27] Gradient has recently announced that there is an option to include a MERV13 filter on their all-weather WHP, but pricing and performance information was not available at the time of publication.

Figure 8. Friedreich Kuhl window air conditioner with FreshAire MERV 13 Filters[28]

Image credit: Friedrich https://www.friedrich.com/merv13_iaq

Unwanted heat gain/loss through portable heat pump hoses

PHPs suffer from lower heating and cooling efficiency compared to window units for several reasons. Single-hose units exhaust air out of the conditioned space through their single hose, causing a negative pressure and inducing infiltration of unconditioned air (Figure 9, right). This is a significant reduction in heating/cooling effectiveness and, for this reason, single-hose PHPs are not included in this MTI. An additional inefficiency, though of a smaller magnitude, is the heat transferred from the hoses into the conditioned space. When in cooling mode (i.e., operating as an air conditioner), the portable unit draws in hot outdoor air, then rejects additional heat to it (Figure 9, left), so the air in the outlet tube is at an even higher temperature. The entire length of

[27] Fast Path to Clean Indoor Air. 350BayArea and Redwood Energy January 2024 Update Presentation. https://docs.google.com/presentation/d/1StoDEv-6hpWK0HHZ4hEFiFXSsS-GU-5TrQA3HJkkQSg/edit#slide=id.g2f3853491c7_1_0.
[28] https://www.friedrich.com/merv13_iaq.

hose is hotter than the conditioned space and will transfer unwanted heat to the room during operation. This effect is captured in the cooling mode test for portable air conditioners and heat pumps and is one reason for the reduced efficiency of PHPs compared to window units.

Figure 9. Operation of single and dual-hose portable air conditioners and heat pumps

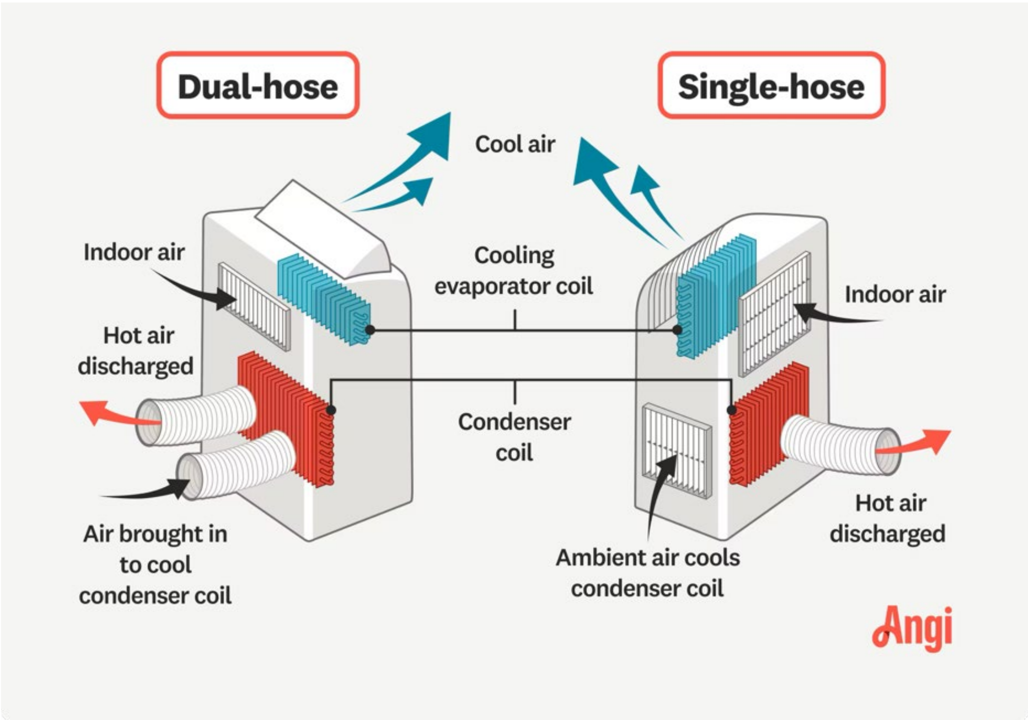
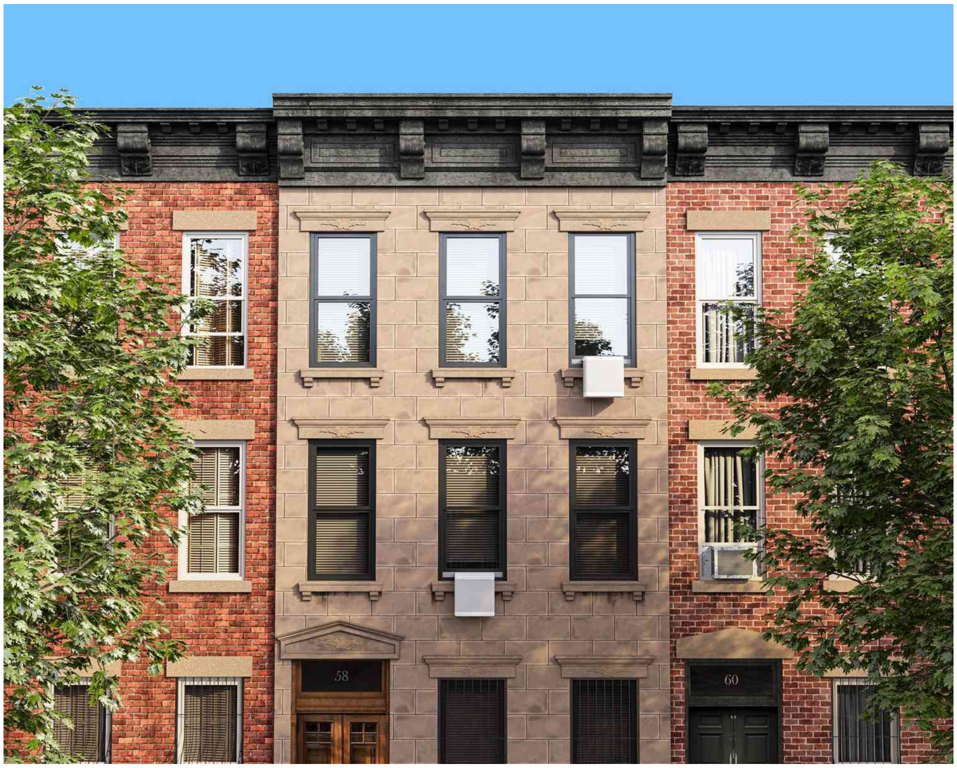


Image credit: Angi https://www.angi.com/articles/how-portable-ac-works.htm.

Aesthetics of outdoor coils for window units

Every air conditioner and air-source heat pump transfers thermal energy to or from outdoor air, which requires a heat exchanger and fan that is connected to the outside. For WHPs, the outdoor coils either protrude directly from the window in the case of a traditional or U-shaped unit or hang outside beneath the window for a saddle bag unit (Figure 10). New saddlebag units have an improved aesthetic compared to the look of window units (one pictured in the brick building to the right in Figure 8), which were found to be preferable to the appearance of PHPs in the market characterization study. In addition to the issue of aesthetics, landlords or homeowner associations may prohibit units that hang out of the window. PHPs do not have an outdoor component but do have hose connections within the window that create an aesthetic issue for some. In contrast, electrical resistance heating such as baseboards and space heaters do not require any outdoor unit. Residential central split heat pumps and ductless mini-splits have outdoor coils, but these can be placed in less conspicuous areas such as on a rooftop or to the side of house when space allows. For larger multifamily buildings there is likely a challenge in placing outdoor coils for any type, although buildings that currently have air conditioning have an existing solution for the placement of outdoor coils. Ideal solutions will minimize the negative aesthetic impact on the outside of a building through either a more visually appealing unit or elimination of the outdoor unit.

Figure 10. Outdoor view of saddlebag heat pumps installed



Challenges in air sealing around units to prevent air infiltration

The majority of RHPs are sold with a kit to seal around the unit during installation to prevent unwanted air infiltration which can then lead to unnecessary energy consumption. A study by National Renewable Energy Laboratory (NREL) found that the installation of a window air conditioner could increase whole house leakage by up to 10%.[29] They estimated that improved installation to mitigate infiltration could lead to 5-10% in cooling savings which was estimated to lead to enough cost savings to pay for the unit over its lifetime. Figure 10 (left) shows the common infiltration pathways of a window air conditioner (or heat pump). The recommendations for improved installation were:[30]

- Use rigid foam panels along the sides of the window unit
- Seal the gaps in the window sash using circular foam backer rod (instead of manufacturer provided foam strips)

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[29] Winkler, J.; Booten, C.; Christensen, D.; Tomerlin, J. (2013). Laboratory Performance Testing of Residential Window Air Conditioners. NREL/TP-5500-57617.
[30] DOE/GO-102013-3920, June 2013.

- Use tape to secure foam panels and air seal all joints

The unit sealed per NREL's recommendation (Figure 11, right) will be more energy efficient but also suffers from poor aesthetics. Many homeowners may not be willing to include duct tape and foam insulation board in the window of their living area. Saddlebag and U-shaped products have a much smaller opening to cover but will suffer from the same issues of sealing around the edges. As this MTI progresses it will be important to work with manufacturers to provide the best insulation materials and design as well as educate building and homeowners on installation practices so that they can maximize their bill savings and that the program maximizes possible energy savings.

Figure 11. Left: Common air infiltration pathways for window heat pumps. Right: Proposed energy efficient sealing by NREL.

Images from Booten, C. (2013). A Homeowner's Guide to Window Air Conditioner Installation for Efficiency and Comfort. Golden, CO: National Renewable Energy Laboratory. DOE/GO-102013-3920.[31]

3 Technical Barriers

3.1 Flammability requirements for refrigerants

Propane (R-290) and isobutane (R-600a) are widely cited as the solution to get to a near-zero GWP for residential and light commercial refrigerants. However, their proponents need to be aware that

[31] https://www.nrel.gov/docs/fy13osti/58187.pdf. Accessed September 17, 2024.

creating acceptable safety regulations is a high barrier that is unlikely to be overcome in the short term. UL 60335-2-40, the equipment design safety standard for HVAC, only permits a maximum charge of 114 grams, which is far from enough for even the smallest residential equipment. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 15 and 15.2, the model codes for refrigerant safety in building codes, explicitly prohibit using highly flammable refrigerants (designated as A3) for residential and light commercial applications.

The ASHRAE 15 Standing Standard Committee has been opposed to allowing the use of A3 refrigerants in any application where they can leak into the occupied space. In 2023, an addendum was proposed for ASHRAE 15.2 that would have permitted using A3 refrigerants in packaged air-to-water heat pumps where all the leakage would be outdoors. The addendum was overwhelmingly defeated, with most opponents citing the lack of research on using these refrigerants in consumer HVAC applications.[32] Despite the interest in applying A3 refrigerants in HVAC applications, little research has been completed in North America, and even in Europe, where charges of up to 988 grams are permitted, there is limited data available.

3.2 Balancing air filtration and energy efficiency and product cost

Integrating air filtration into HVAC products can significantly benefit indoor air quality, but this also creates challenges around energy consumption and cost. Adding physical filtration media upstream of the fan can remove micron-sized physical particles from the air but will also increase the pressure drop of the system. To achieve the same airflow, the fan may have to use more energy to provide the same heating or cooling, thus reducing the heat pump's efficiency. Depending on the system's design, this may require a slightly larger fan to achieve the same desired flow rates.

HVAC filters are often rated with the MERV rating system, which is an indicator of the efficiency of particle removal. The rating is from 1 to 20 based upon the ability to remove particles within the range of 0.3 to 10 microns with high numbers representing higher filtration efficiency. MERV 13 filters can filter >50% of particles 0.3 – 1.0 microns, >85% of particles 1.0 – 3.0 microns and >90% of particles 3.0 – 10.0 microns. This is a commonly recommended filter efficiency level for removal of wildfire smoke[33] and the removal of airborne virus and bacteria.[34] MERV-13 filters typically use electrostatic charge to increase filtration efficiency without including more physical material, which increases pressure drop. Recent studies have reported mixed results on the energy consumption impact on a central ducted forced air HVAC system's energy consumption through the use of higher MERV filters. An experimental study showed no change in HVAC energy

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[32] ASHRAE Committee Chair Expects 2025 or Later for Approval of Higher R290 Charge for Heat Pumps in U.S. Hydrocarbons. Accessed April 16, 2024. https://hydrocarbons21.com/ashrae-committee-chair-expects-2025-or-later-for.

[33] https://www.hsph.harvard.edu/healthybuildings/2023/08/15/protecting-your-health-from-wildfire-smoke-spotlight-on-filters/.

[34] https://www.ashrae.org/technical-resources/filtration-and-disinfection-faq.

consumption between MERV 8 and MERV 13 filters for a central-ducted system,[35] while several energy modeling studies predicted energy increases of 3 to 10% for upgrades to MERV 13 from MERV 10 and MERV 8, respectively.[36]

The energy consumption is typically correlated with the fan runtime, which implies that variable-speed systems may suffer a larger efficiency drop compared with single-speed systems. The existing literature focuses on ducted central HVAC systems, which could differ from RHPs due to the difference in geometry, airflow rates, filter size, and other parameters. Future lab testing and manufacturer engagement will help quantify the cost and energy penalty of high-efficiency air filtration for RHPs and whether a specific intervention is required to create RHPs with air filtration that are affordable from a perspective of both upfront and operating costs. Despite uncertainty about the efficiency and cost, the existing room air conditioner from Friedrich shows there is a path towards integrating air filtration into RHPs.

4 Competitive Landscape

This section examines the Strengths, Weaknesses, Opportunities, and Threats of the MTI technologies and competing products. An objective and thorough SWOT analysis can reveal insights as to a future product strategy and also help identify key barriers to overcome. The comprehensive SWOT is found in Table 2.

4.1 Key strengths

One of the primary strengths of RHPs is their low installation cost. Unlike central HVAC systems or ductless mini-splits, which usually require professional installation, field refrigerant charging, and puncturing the building envelope, RHPs can be installed by the consumer or building maintenance staff. Window units are place over a sill and through-the-wall units are inserted into a sleeve.[37] This capability greatly reduces the overall cost, making them an attractive option for budget-conscious consumers. While the upfront equipment cost of ductless mini-splits can be comparable, professional installation typically makes these systems more expensive than RHPs.

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[35] Zhang et. al., *Impact of high efficiency filters on energy consumption,* International Filtration News, August 5, 2021.
https://www.filtnews.com/impact-of-high-efficiency-filters-on-energy-consumption/.

[36] Zaatari, M. Novoselac, A., and Siegel, J., "The relationship between filter pressure drop, indoor air quality, and energy consumption in rooftop HVAC units," *Building and Environment*, Volume 73, 2014, Pages 151-161, https://doi.org/10.1016/j.buildenv.2013.12.010.
Faulkner et. Al., MERV 13 Filtration for Office Buildings During COVID-19 Pandemic, Proceedings of the 12th International Symposium of Heating, Ventilation, and Air Conditioning, Seoul, Korea. November 24-26, 2021.

[37] In this MTI, we consider through-the-wall heat pumps for replacement only, where an existing through-the-wall AC unit can be removed, and a heat pump can be installed without modification of the building envelope.

RHPs are highly efficient when compared to other electric heating options such as space heaters, baseboards, and electric wall heaters. They utilize a refrigeration cycle to transfer heat, which is inherently more efficient than generating heat through resistance. This efficiency translates into lower operating costs and reduced energy consumption, making RHPs an environmentally friendly option. This is true specifically for replacing electric heating sources, but not necessarily for gas.

Another significant advantage of RHPs is their ability to provide both heating and cooling. This dual functionality is unique among lower-cost consumer appliances. While most window units are traditionally used for cooling only, heat pumps can switch modes to provide warmth in colder weather, offering year-round climate control from a single device. This feature makes them particularly appealing in regions with moderate climates where extreme temperatures are less common.

Lastly, portability can be a positive feature for renters who may wish to make the choice to upgrade to a better source of space conditioning but also want the ability to take it with them when they move out of their current home. The movement from one home to another is a positive feature of room and PHPs, but PHPs are somewhat easier to move within a home. This can allow a user to move it to the room where its most needed by season or easily stow in months where heating and cooling are not needed.

4.2 Key weaknesses

Despite their benefits, the initial cost of RHPs is generally more expensive than the combined cost of a window air conditioner and a space heater. This higher initial cost can deter some consumers, particularly those on a tight budget who may not see the value in the added expense for the combined functionality.

The necessity of a single- or double-hung window for installation is another current limitation for the window versions of this technology. This requirement restricts the use of WHPs in buildings with different window designs or those without suitable windows at all. This limitation can reduce the potential market for these units, as not all consumers will have compatible windows for installation.

Even with their higher efficiency, some consumers may experience higher heating bills when changing from gas to electric heating because of the high price of electricity in California compared to gas. This potential increase in utility costs can be a significant drawback for consumers considering an RHP as an alternative to their existing heating system as noted in the market characterization.[38] With some of the lower cost RHPs, low temperature performance is an issue, too. Users may be unaware that the heat pump stops operating when the temperature drops below 40°F, causing discomfort if no other heat source is readily available or an inconvenience if you have to switch to a backup heating source. This weakness in heating

[38] Consumers were found to be very aware of their electricity usage because of high rates and hesitant to increase their energy bills. Appendix D: Market Characterization Report for Room Heat Pumps.

performance is magnified in PHPs which generally have lower efficiency and can have additional losses through heat transfer through the hose and infiltration of outdoor air.

4.3 Key opportunities

Consumers who already use window or portable AC units have accepted the form factor and self-installation process. These consumers could upgrade to an RHP to gain the additional benefit of heating and more efficient cooling. Similarly, landlords and property managers with through-the-wall AC units have the wall sleeve that would make installing a through-the-wall heat pumps an easy upgrade option, especially if they are facing potential maintenance costs for aging natural gas or electrical heating systems and with providing tenants with supplemental cooling during heat waves.

Older homes with forced air furnaces often have certain rooms or floors that are not adequately heated. RHPs can provide targeted zone heating, addressing these inadequacies without the need for renovations. This application is particularly relevant in homes where central systems struggle to maintain consistent temperatures.

PHPs and RHPs give renters and leaseholders the ability to upgrade their HVAC systems while overcoming restrictions on modifications to the property. RHPs, with their low installation costs and ease of installation, are an ideal solution for this demographic, offering an upgrade without permanent changes.

By offering a modern, efficient heating and cooling solution, landlords can improve tenant satisfaction and potentially increase property values without significant investment.[39] The enhanced aesthetic of the new Type 4 saddlebag heat pumps will create a more visually appealing product that may circumvent the objections from landlords about unsightly window air conditioners.

4.4 Key threats

Substituting gas with electric heating can be expensive, depending on the specific circumstances.[40] This transition could negatively impact consumers, especially those in economically disadvantaged communities, by increasing utility bills. Ensuring that the move to electric heating does not adversely affect these communities is crucial. The poor low temperature heating performance of many RHPs may leave consumers dissatisfied, particularly in regions with harsh winters. Inadequate heating during extreme cold weather events can also pose safety risks, making it essential for manufacturers to address these performance issues. Many consumers may hesitate to pay the premium for an RHP compared to a window AC unit, especially given the wide availability of inexpensive space heaters. The initial cost difference can be a significant barrier, and convincing consumers of the long-term benefits and cost savings is essential to drive adoption.

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[39] See the property manager survey in the Appendix D: Market Characterization Report for Room Heat Pumps.
[40] The change in utility bills from gas is dependent upon the building type, insulation, windows, thermostat setting, and other factors. See the Bill Impacts section for more detail about general findings.

Table 2. SWOT analysis of room and portable heat pumps

Product	Strengths	Weaknesses
MTI Product – Portable Heat Pump	• Flexibility – can be installed in most operable windows • Installation does not require certified technicians • Plug directly into 120V outlet • Can be removed and stored during mild months • Can be moved into different rooms relatively easily • More efficient than electric resistance heating for mild weather (>40°F) • Only plug-in product type for year-round space conditioning (heating and cooling)[41]	• Low efficiency compared to central and mini-split heat pump technologies • Takes up floor space (and more than space heater) • Cannot open window in which it is installed • Most do not provide heating below 40°F • Possibility for poor condensation management in some climates • Costs more to operate than gas heater in some cases
MTI Product – Room Heat Pump	• Low total first cost (product and installation) • Installation does not require certified technicians • Plug directly into 120V outlet • Efficiency and performance comparable to ductless mini-split HPs for new saddlebag products • Increased efficiency compared with space heaters • Cheaper to operate compared to resistance heaters • Newer form factors (U-shape, saddlebag) improve the aesthetics, maximize window view, and allow window operation, making year-round installation more attractive • Only plug-in product type for year-round space conditioning (heating and cooling)	• Limited to hung windows and min. width required • Unable to lock window (minimized with saddlebag units low sash position) • Cannot install security bars over window • Cannot open window in which its installed for compact form factor (not true for U-shape or saddlebag) • Colder climate RHPs are more expensive than room A/C and space heater • Higher operating costs compared to gas heating in some cases

[41] Only product here refers to the total MTI product of RHPs and PHPs.

Product	Opportunities	Threats
MTI Product – Portable Heat Pump	• Leverage consumers who have existing portable A/C units to replace with HP • Potential for electricity bill savings for any consumers using electrical resistance heating • Consumers looking for environmental product may choose heat pump • DIY consumers who want a complete HVAC (heating + cooling) could be attracted to this product • Leverage consumers looking to condition a small space of a large home (displacement)	• Higher noise compared to some electrical products • Poor performance at lower temperature may cause consumers to favor their other heating means • Meltwater and condensate not handled properly – creates moisture problem in dwelling
MTI Product – Room Heat Pump	• Leverage consumers who have existing room A/C units to replace with HP • Potential for electricity bill savings for any consumers using electrical resistance heating and also those with older inefficient window AC • Consumers looking for environmental product may choose heat pump • DIY consumers who want a complete HVAC (heating and cooling) could be attracted to this product	• MF building owners exclude the use of WHPs • Consumers buy a HP product that does not work in their climate – creates cold safety risk • Meltwater and condensate not handled properly – creates moisture problem in dwelling • RHP set up in Auto mode and fights with existing heating – wasting energy • Some older homes may have issues accommodating up to 10A due to limited electrical capacity if changing from gas and no current window AC

Table 3. Strengths and weaknesses of space conditioning products for small residential dwellings

Product	Strengths	Weaknesses
Incumbent Technology - Portable/Window A/C	• Can be installed in most operable windows (for portables) • Installation does not require certified technicians • Plug directly into 120V outlet • Low cost compared to heat pumps • Product is more mature with more options than HP	• Can be installed during the cooling season and removed for rest of year • Compressor indoors creates more noise • Prone to air infiltration and leaking around window

Product	Strengths	Weaknesses
Incumbent Technology – Electrical Space Heating	• Many different types of products available with different types of heat delivery and noise levels • Many low-cost products <$100 • Performance is independent of outdoor temperature	• Limited heating capacity on single circuit compared with HP (~3x less at peak) • Costs more than gas or heat pump to operate • Poses a safety/fire hazard • Take up floor space • Does not provide air filtration
Incumbent Technology – Electrical Baseboard Heating	• Quiet zone heating in compact form • Relatively simple equipment low cost for maintenance/installation compared to a central HVAC • Performance is independent of outdoor temperature	• Heating is highly localized within room • Costs more than gas or heat pump to operate • Poses a safety/fire hazard • Does not provide air filtration
Incumbent Technology – Central Forced Air HVAC (gas furnace)	• Provides a high level of cooling/heating capacity • Conditions multiple areas with a single system • Can provide enhanced IAQ through filtration • Typically, lower utility bills for heating compared to electrical • Straightforward compatibility with smart thermostats	• Extremely expensive/difficult to install as a retrofit in an existing building that does not have ducting • Ducts can be source of energy loss, spot for mold accumulation • High costs for repair/replacement • Often heating is from gas furnaces with high GHG emissions • Refrigerant lines can leak
Competing Technology – Ductless Mini Split	• Highly configurable product that allows for efficient cooling and heating at a variety of price points and performance levels • A half-way point compromise between the cost and complexity versus performance of residential split direct expansion systems and window units • Can be installed by advanced DIYers in some cases • Cold-weather heat pumps available for low temperature heating	• The requirement of outdoor condenser limits the applicability for many multifamily buildings • Installation requires holes in the building envelope, much more expensive and complex compared to RHPs • Does not provide ventilation or air filtration
Competing Technology – Packaged Terminal Heat Pump	• Standardized product with many price competitive options • Provides outdoor air ventilation	• Requires contractor installation which is more expensive

Product	Strengths	Weaknesses
		• Typically installed in commercial hospitality although used in multifamily as well • Not sold through consumer retail channels
Emerging Technology – Single Packaged Vertical Heat Pump	• Highly configurable product that allows for efficient cooling and heating at a variety of price points and performance levels • Aesthetically pleasing • Can include ventilation and energy recovery ventilation • Typically, does not occupy window opening	• High product cost compared with RHPs • Requires contractor installation

5 Codes & standards

5.1 Federal standards

There are separate federal standards governing the cooling performance of room air conditioners and portable air conditioners, which cover RHPs and PHPs, respectively. While both appliance categories use the metric named CEER, these metrics are calculated differently based upon different test procedures and thus cannot be compared directly. Currently there is no mandatory test procedure for heating performance of room and PHPs, but EPA has recently released the final version of the ENERGY STAR voluntary test procedure for RHPs, defining the Heating Energy Efficiency Ratio (HEER) which will be discussed here.

Federal standards for cooling of portable air conditioners (and portable heat pumps)

In California, the minimum CEER rating for portable air conditioners is determined by the SACC as seen in Table 4. As of February 1, 2020, portable air conditioners available for sale in California must adhere to the federal test[42] and comply with state standards detailed in the California Code of Regulations (CCR).[43] SACC is intended to replace the ASHRAE BTU/h capacity, but many manufacturers list both, since the ASHRAE capacity is a more direct relationship with the size of the room the unit can cool.

Using the specified test procedure, SACC provides a realistic estimate of a portable air conditioner's cooling capacity by considering various real-world conditions and external heat sources, offering a practical measure of performance for consumers. In contrast, ASHRAE cooling capacity measures the cooling ability under a single, specific set of conditions (95°F and fixed humidity), providing a consistent but potentially less realistic benchmark for comparing different units. It is important to note that existing portable AC systems might have equivalent ASHRAE cooling capacities, but they may not have the same SACC.

Table 14. CEER rating of portable AC based on SACC

Seasonally Adjusted Cooling Capacity (SACC) [kBTU/h]	Combined Energy Efficiency Ratio (CEER)
4	5.62
5	6.10
6	6.51
7	6.88
8	7.22

[42] As outlined in 10 CFR 430.23 (dd) (Appendix CC to subpart B of part 430).

[43] Title 20, section 1605.3 (d) (1).

Seasonally Adjusted Cooling Capacity (SACC) [kBTU/h]	Combined Energy Efficiency Ratio (CEER)
9	7.54
10	7.83
11	8.11
12	8.37
13	8.61
14	8.85
15	9.07
16	9.28
17	9.49
18	9.69
19	9.88
20	10.06

Since the first set of federal standards for Portable AC/HP will not take effect until 2025, the next opportunity to update those standards will be in 2031.

The original portable AC federal test procedure was developed in 2016, which is still what most manufactures have used to be able to sell their products in California and/or market an efficiency level (CEER) to customers outside of California. However, that test procedure failed to incorporate variable speed performance. The new test procedure proposed will favor the type of variable speed inverter equipment used in many PHPs (and efficient portable ACs).[44]

Federal Standards for Cooling Efficiency of Room Air Conditioners (and Room Heat Pumps)

Since the cooling performance of room ACs and HPs have been federally regulated for many years, the California Energy Commission (CEC) is "preempted" from creating more stringent standards than the federal standards, so Title 20 and federal standards are the same, at least with respect to cooling efficiency. Unlike portable AC and HP, which use the same equation for minimum efficiency, room standards have separate, less stringent requirements for ACs with reverse cycle (i.e., heat pumps). This is likely in recognition of the fact that it is harder to optimize for cooling performance when also providing heat with the same compressor.

Relative to portable ACs, the federal standards for room ACs are already fairly stringent and will become more stringent when compliance with the new standards take effect in 2026. From June 1, 2014, to May 26, 2026, room air conditioners are required to adhere to the efficiency ratings (CEER) standard as outlined in 10 CFR 430.32(b). However, starting May 26, 2026, the standards for room ACs will be revised to mandate more efficient equipment. The specific efficiency ratings for each equipment type are detailed in Table 5 below.

[44] Energy Conservation Program: Test Procedure for Portable Air Conditioners. 10 CFR Parts 429 and 430.

Table 5. Standards for room AC combined energy efficiency ratio: reduced table covering classes with capacity from 8,000 to 20,000 BTU/h

Equipment Class	CEER Rating (June 2014 - May 2026)	CEER Rating May 26, 2026 +
3. Without reverse cycle, with louvered sides and with a certified cooling capacity of 8,000 to 13,999 BTU/h	10.9	16
4. Without reverse cycle, with louvered sides and with a certified cooling capacity of 14,000 to 19,999 BTU/h	10.7	16
8a. Without reverse cycle, without louvered sides and with a certified cooling capacity of 8,000 to 10,999 BTU/h	9.6	14.1
8b. Without reverse cycle, without louvered sides and with a certified cooling capacity of 11,000 to 13,999 BTU/h	9.5	13.9
9. Without reverse cycle, without louvered sides and with a certified cooling capacity of 14,000 to 19,999 BTU/h	9.3	13.7
11. With reverse cycle, with louvered sides, and with a certified cooling capacity less than 20,000 BTU/h	9.8	14.4
12. With reverse cycle, without louvered sides, and with a certified cooling capacity less than 14,000 BTU/h	9.3	13.7
14. With reverse cycle, without louvered sides, and with a certified cooling capacity of 14,000 BTU/h or more	8.7	12.8
15. Casement-Only	9.5	13.9
16. Casement-Slider	10.4	15.3

The current test procedure for room AC and HP already accounts for variable speed efficiency, which should provide higher CEER ratings for inverter products, including WHPs. Since minimum heating efficiency is not regulated, it is not preempted and, therefore, the CEC is able to set (through Title 20) minimum heating efficiency requirements that effectively ban window ACs with resistance heating from being sold in California. It is important to note that the minimum efficiency required for a room air conditioner without reverse cycle is a CEER value of 16 (for 10,000 BTU/h cooling capacity), but the CEER required for an RHP (room air conditioner with reverse cycle) of the same capacity is only 14.4. The 10% reduction of required cooling efficiency is because it is more challenging to design a heat pump with the same cooling efficiency as an air conditioner only. This is due to the competing factors of optimizing the heat pump for cooling and heating cycles.

ENERGY STAR voluntary metric for heating efficiency of room heat pumps

A new metric, Heating Energy Efficiency Ratio (HEER), has been established by the EPA for Room Air Conditioners with Reverse Cycle (i.e., RHPs) in a new ENERGY STAR test procedure.[45,46] The goals for establishing the test procedure are to 1) provide a representative measure of heating mode performance for room ACs that is both repeatable and reproducible and to 2) offer an overall heating efficiency metric as well as distinguish performance at specific temperature conditions of particular interest, including colder conditions (i.e., <5°F).

HEER for heating will be a complement to CEER for cooling. The HEER metric is not currently included in federal efficiency standards; however, heating mode data and heating mode performance criteria will be included in the new ENERGY STAR specification for room heat pumps. This effort is in reaction to the increased desire for electrification products and seeks to have DOE and EPA work together by using ENERGY STAR as a trial of the new metric before enacting efficiency standards.

This test defines a heating efficiency metric, HEER, with test points at dry bulb outdoor temperatures ranging from 62°F down to 5°F depending upon the type of heat pump. The test defines four categories of RHP depending upon the operation temperature and defrost strategy:

- **Type 1 heat pump**: An RHP that does not have active defrost or for which the specified compressor cut-in and cut-out temperatures are not both less than 40˚F.
- **Type 2 heat pump:** An RHP that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 40˚F but not both less than 17˚F.
- **Type 3 heat pump:** An RHP that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 17˚F but not both less than 5˚F.
- **Type 4 heat pump:** An RHP that has active defrost and for which the specified compressor cut-in and cut-out temperatures are both less than 5˚F.

The EPA plans to release a room heat pump HEER specification for ENERGY STAR qualification by the end of 2024, but as of November 8, 2024, the draft specification has not yet been released.

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[45] https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Draft%201%20Test%20Method%20to%20Determine%20Room%20Air%20Conditioner%20Heating%20Mode%20Performance%20Webinar.pdf.

[46] https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Draft%201%20Test%20Method%20to%20Determine%20Room%20Air%20Conditioner%20Heating%20Mode%20Performance.pdf.

5.2 California standards

Title 20 standards for portable air conditioners (and heat pumps)

As noted above, as of February 1, 2020, portable air conditioners available for sale in California must adhere to the federal test[47] and comply with state standards detailed in the CCR.[48] While the DOE had introduced this standard in 2016, a final ruling was not established then. However, the DOE has since finalized the ruling, with the standard set to be effective from January 1st, 2025. Since this was a previously unregulated product category, California was able to make these requirements effective as of February 1, 2020, a month before the federal requirements were formally adopted, and almost five years before they will be enforced.

Title 20 standards for room air conditioners and heat pumps

Since Room ACs and HPs have been federally regulated for many years (cooling performance only), the CEC is "preempted" from creating more stringent standards than the federal standards. As a result, Title 20 and federal standards are the same, at least with respect to cooling efficiency. See Section 2.2 for more details.

5.3 Non-energy regulations

Low-GWP Refrigerants

Many RHP products on the market today utilize R410A. R410A is a higher GWP refrigerant that will be replaced by newer, lower-GWP alternatives. California Senate Bill 1206 bans the sale/import of bulk refrigerants with a GWP over 1500 by 2030, including R410A. The EPA has proposed banning R410A in new ACs and HPs by January 1, 2025.

The most popular alternative refrigerant for these products is currently R32. R32 has become widely adopted in Asia as the next refrigerant of choice in residential HP and AC applications. This shift in Asia encourages regional manufacturers to export residential HVAC products designed for use with R32. However, R32 refrigerant has an uncertain future in California. The Intergovernmental Panel on Climate Change (IPCC)[49] completed their Sixth Assessment Report (AR6) [50] in 2023. AR6 revised the calculation for determining GWP upward for R32. According to the IPCC, R32 now has a GWP very slightly above the future 750 GWP limit for residential AC and HP products. This changed status has not been adopted by CARB, who continue to use the AR4 definitions for R32 which calculates a GWP below 750. SB 1206 prohibits the sale of bulk

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[47] As outlined in 10 CFR 430.23 (dd) (Appendix CC to subpart B of part 430).
[48] Title 20, section 1605.3 (d) (1).
[49] The IPCC is the United Nations body for assessing the science related to climate change.
[50] IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: G10.59327/IPCC/AR6-9789291691647. https://www.ipcc.ch/report/sixth-assessment-report-cycle/.e.

refrigerants with a GWP over 750 after January 1, 2033. This creates a level of uncertainty for manufacturers looking to commit to a technology/design in the mid to long term.

Other alternatives to R410A include R454B, R452B, R454A, R454C, R457A. These alternatives are A2L refrigerants, which have low flammability and low toxicity. Charge limits for low-flammability A2L refrigerants are not likely to be a concern for RHPs.

Natural refrigerants are often cited as the future of refrigerant technology since they typically have very low GWP (< 10). Propane (R290) is a natural refrigerant that works well in air source heat pumps however it is considered to be highly flammable (category A3) and thus has limitations on the amount that can be used in buildings. More is be discussed on the refrigerant in the Greenhouse Gas section of Product Performance.

6 Product performance

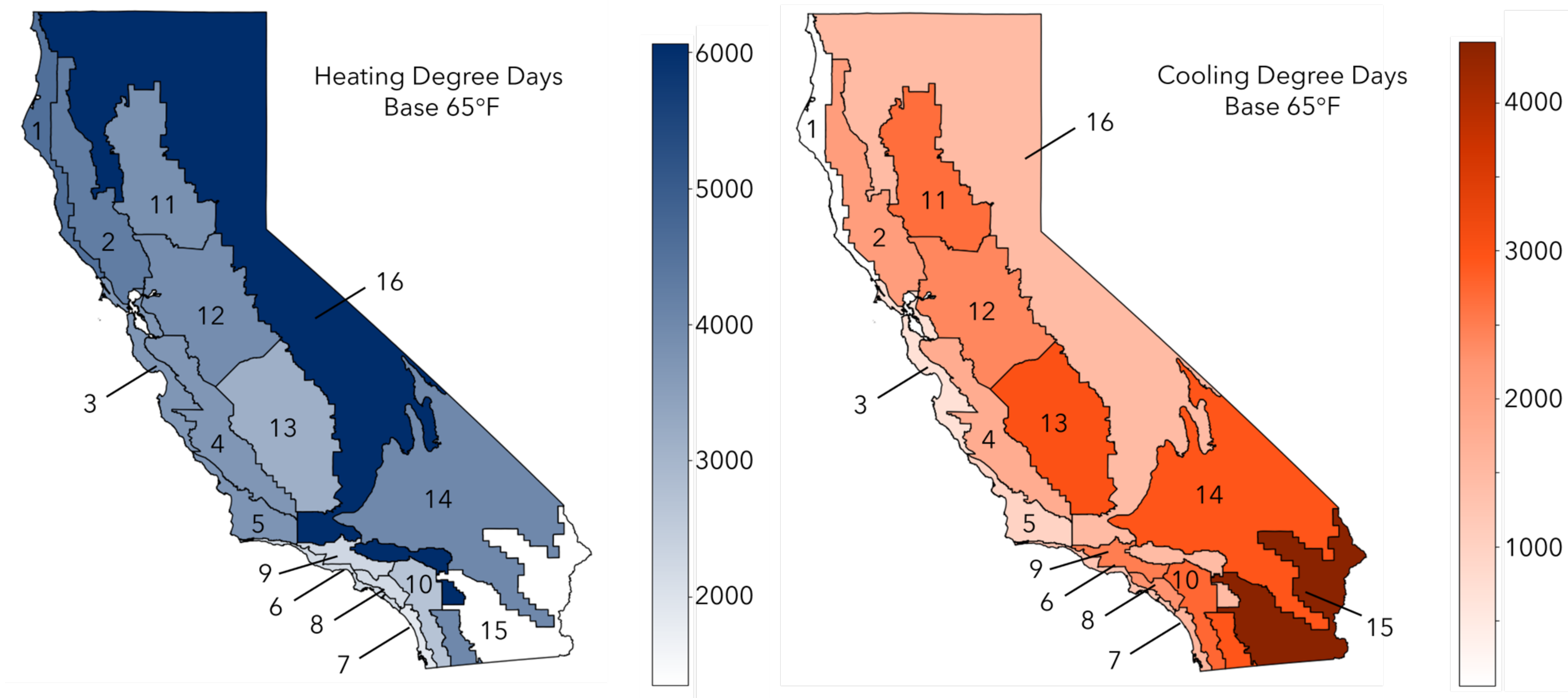
6.1 Methodology/Approach

California climate

Energy modeling was the primary means of assessing product performance used for this report. If the MTI transitions into the next phase, targeted field and lab testing can better inform energy savings, bill impacts, product specifications, and required interventions. California has a very diverse climate, encompassing 7 different ASHRAE climate zones, the most of any state. Because of this California has its own 16 climate zones established for Title 24 building codes. These zones are shown in Figure 12, along with a map of the heating and cooling degree days by climate zone.[51] Despite the diversity of climate across the state, the population is primarily focused in ASHRAE climate zones 3B and 3C, which is relatively warm with mild cooling requirements with 98% of the population living where the lowest temperature in a typical year is 20°F or higher and 38% with the lowest temperature of 35°F in a typical year. This is an important consideration as CalMTA looks to find heat pumps suitable for California, which do not have as stringent requirements for cold temperature performance. As discussed previously, RHPs designed to operate down to 0°F can be significantly more expensive than those needed to heat at 30°F or 40°F, due to the size and performance required from the compressor and heat exchangers.

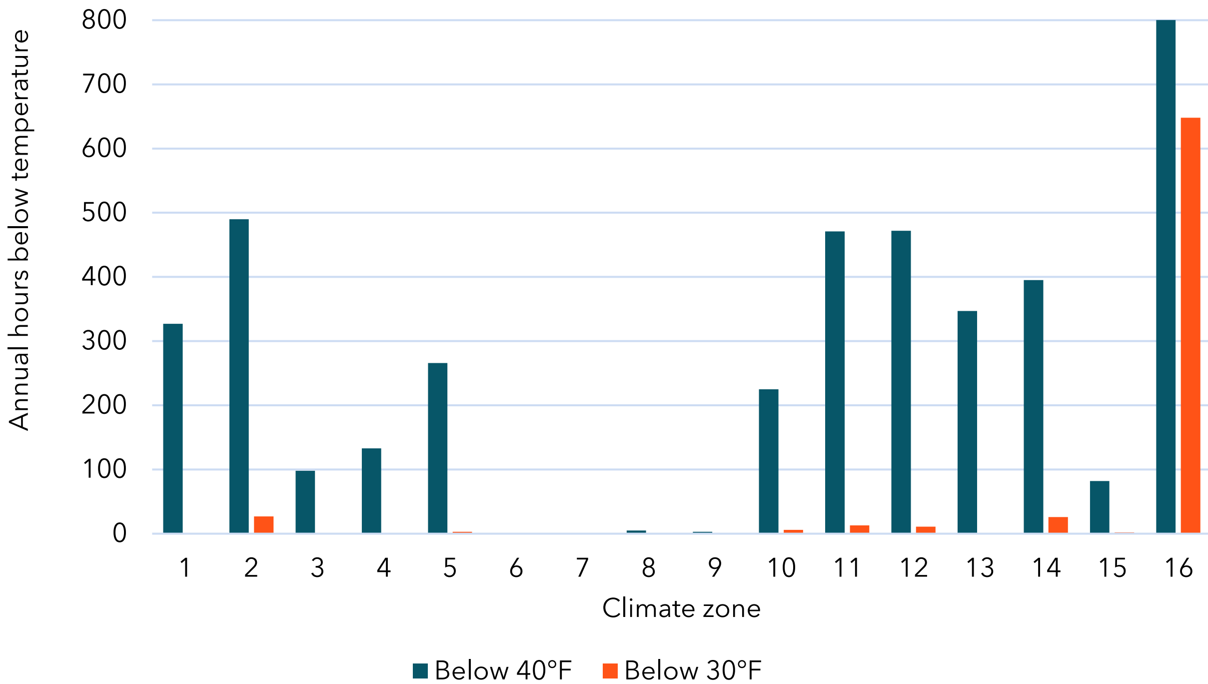
[51] See https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php#:~:text=Cooling%20degree%20days%20(CDDs)%20are,two%20days%20is%2033%20CDDs for an explanation of cooling degree days.

Figure 12: Heating and cooling degree days by climate zone in California



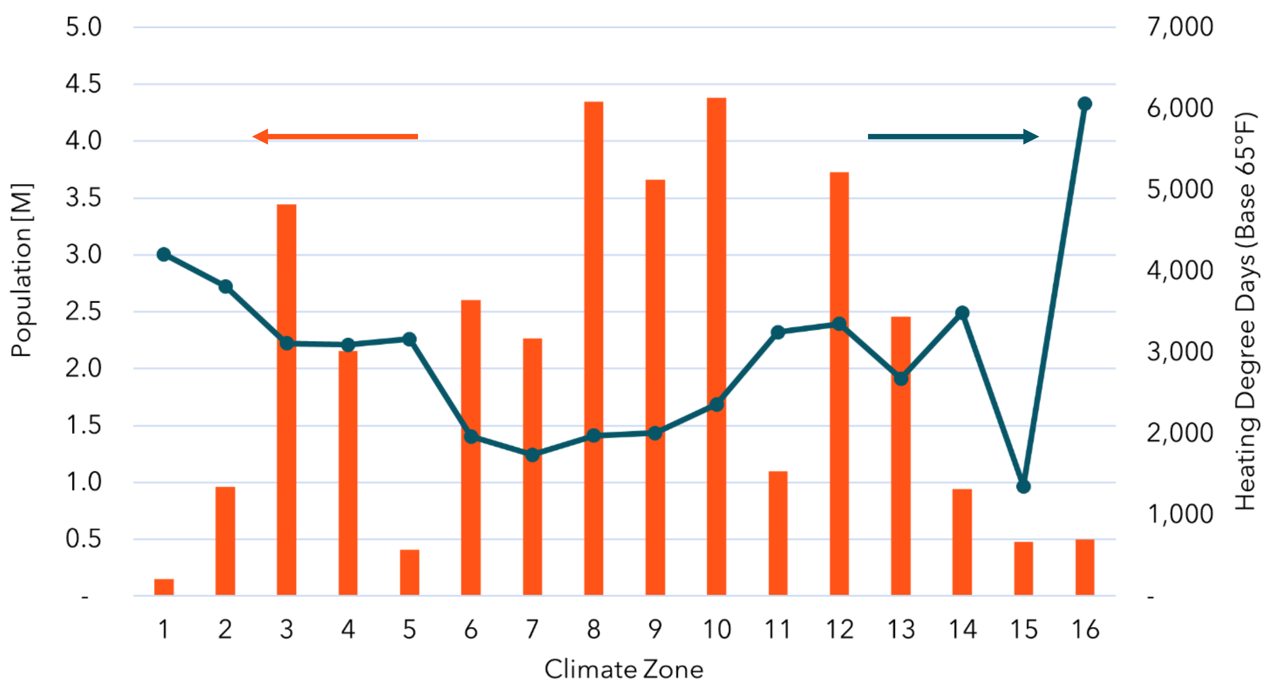
For example, the NYCHA Clean Heat for All Challenge requires that a WHP operate efficiently down below 17°F, while the vast majority of Californians will not observe this temperature for the entire heating season. Figure 13 shows the amount of time spent below 42°F and 32°F in California for a typical year; most California climate zones only see a limited number of hours below freezing.

Figure 13. Annual time spent below 40°F and 30°F by climate zone, based upon typical weather year



There is a wide variation in the population in each California climate zone with the two coldest climates (climate zone 16 and climate zone 01) having populations less than 500K, while many of the climate zones with milder heating requirements (HDD < 3,000) have populations between 2.0M and 4.5M (Figure 14). Product strategy and interventions may focus on a high-volume product to meet the needs of 98% of California residents in climate zones 2 through 15, with a more targeted product/intervention for the colder climates.

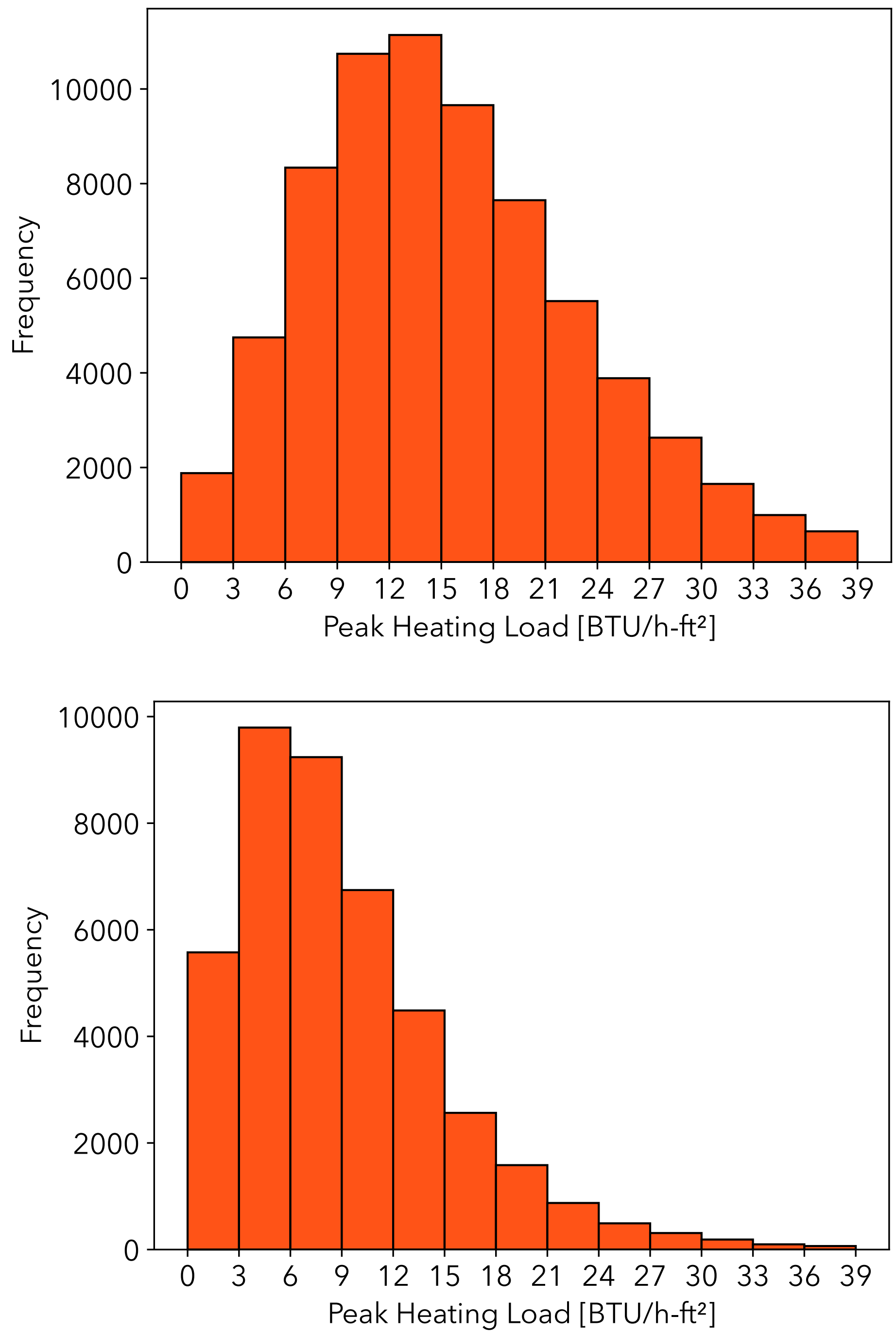
Figure 14. Population and Heating Degree Days for California Climate Zones*



*Note: this graph is zoomed in for detail, the annual hours below 40°F for climate zone is 1904.

This can be an opportunity, since the mild heating seasons in most areas lead to low heating loads, which can be more easily met by small WHPs. ResStock data show that the median peak heating load for multifamily is less than 10 BTU/h-ft^2 for more than half of climate zones (and the most densely populated ones) as seen in Figure 15. This indicates that a single 10,000 BTU/h WHP could provide adequate heating to an open area of 1,000 ft^2 in many cases. There are additional considerations based on the number of rooms in a dwelling, low temperature performance, and accounting for extreme weather events, but this shows generally that many California multifamily buildings would be well-suited to WHPs. Another important finding from the ResStock data is that the required heating load for single-family buildings is approximately 50% larger for the same area (Figure 15). The larger heating load per area, and the larger area of single-family homes, makes the use of WHPs as a primary heating source in single-family homes more challenging, as one might expect.

Figure 15. Peak annual heading loads for multifamily (top) and single-family (bottom) homes in California, from ResStock



Energy modeling methodology

Building energy modeling was performed using EnergyPlus, the open-source DOE software, with building models developed by the Database for Energy Efficient Resources (DEER) and DOE to represent both single and multifamily California homes with comparable energy consumption. The DEER prototype buildings are single-family attached (1 story), single-family detached (2 story), and multifamily with 12 units (2 story).[52] These models have been calibrated to match the energy use intensity from RASS 2019 survey data and are similar to the vintage of 1975 to 1985. The models are shown in Figure 15. The two models are run simultaneously in each case and averaged to minimize orientation effects. In all cases there is an exterior wall surrounding the building that affects shading, but these have been removed in one building in each rendering to show the geometry of the building. Some additional information about the buildings is included in Table 6.

[52] https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M398/K072/398072858.PDF.

Figure 16. Buildings used for energy modeling[53]

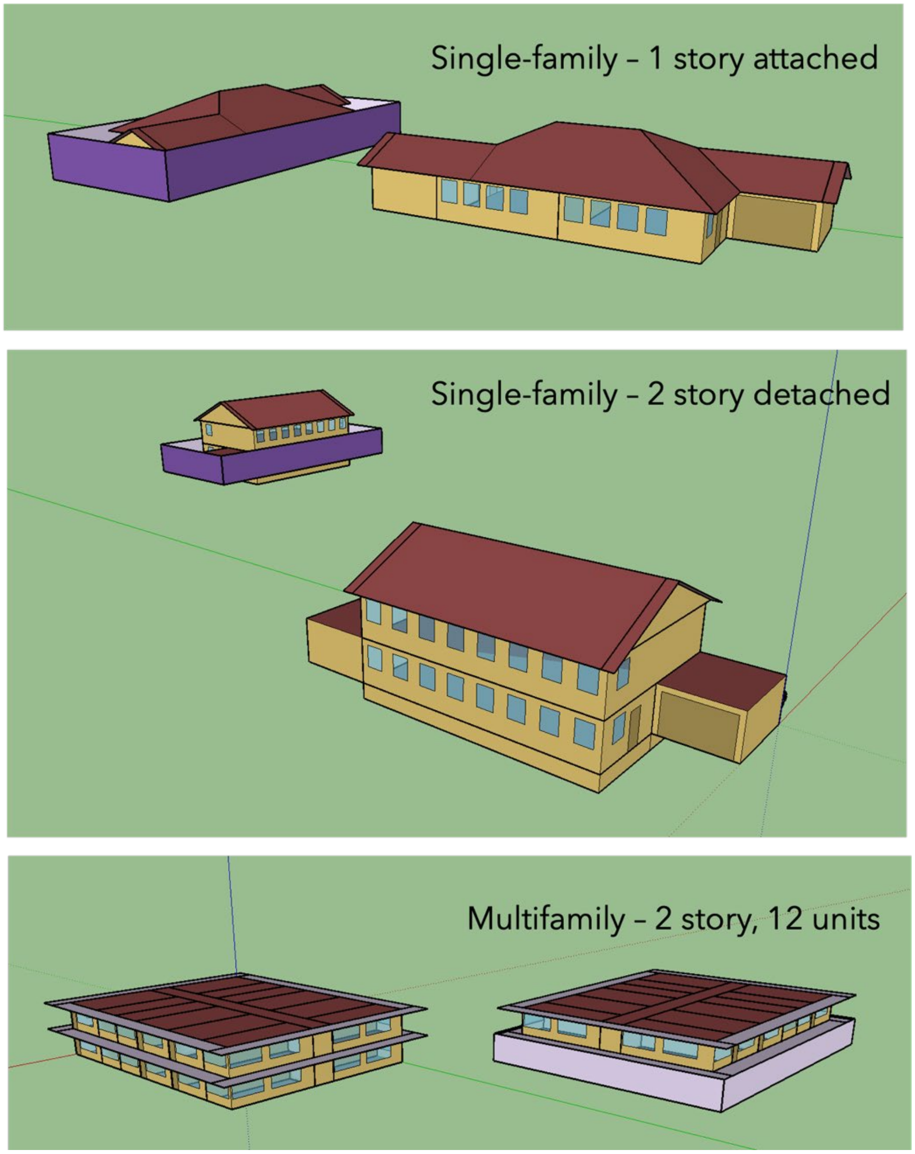


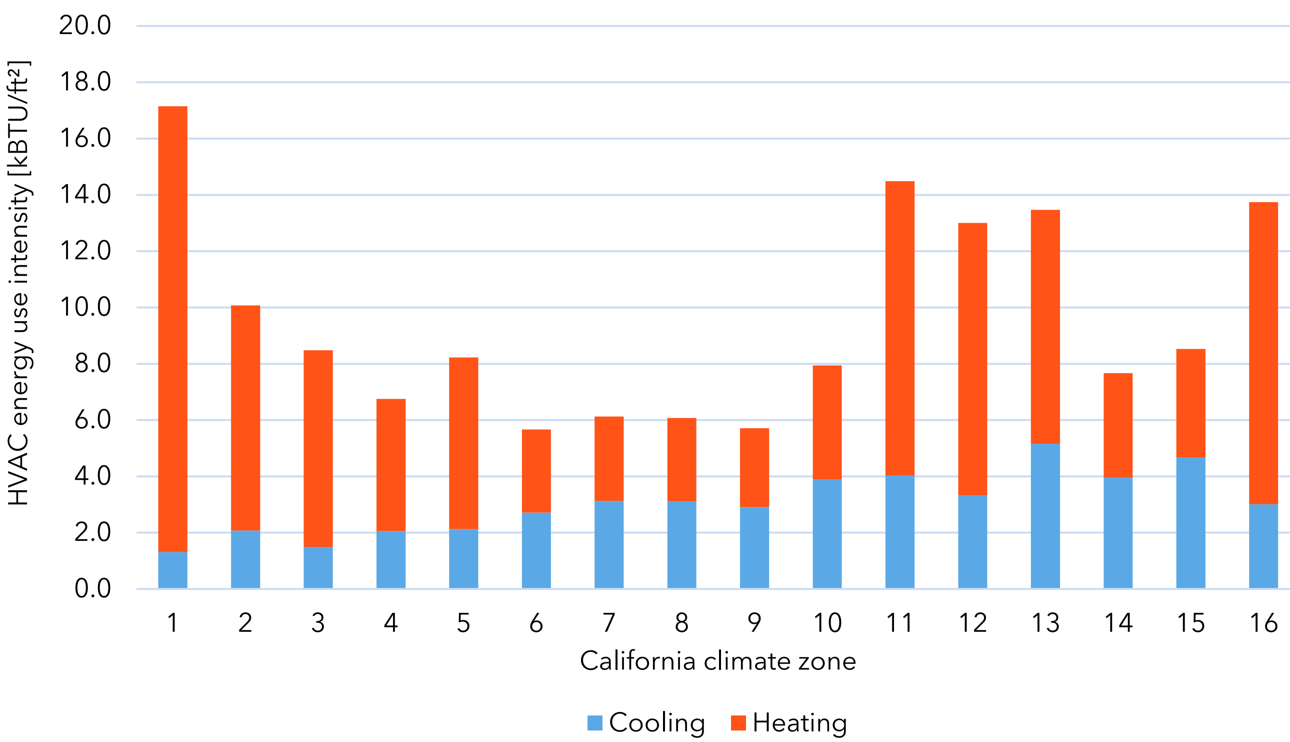
Table 6. Description of buildings used for energy modeling

Source	Vintage	Type	Stories	Units	Area/Unit [ft²]
DEER	1975-1985	Multifamily	2	12	1,024
DEER	1975-1985	Single-family attached	1	2	727
DEER	1975-1985	Single-family detached	2	1	2,906

53 EnergyPlus IDF building models visualized in Sketchup.

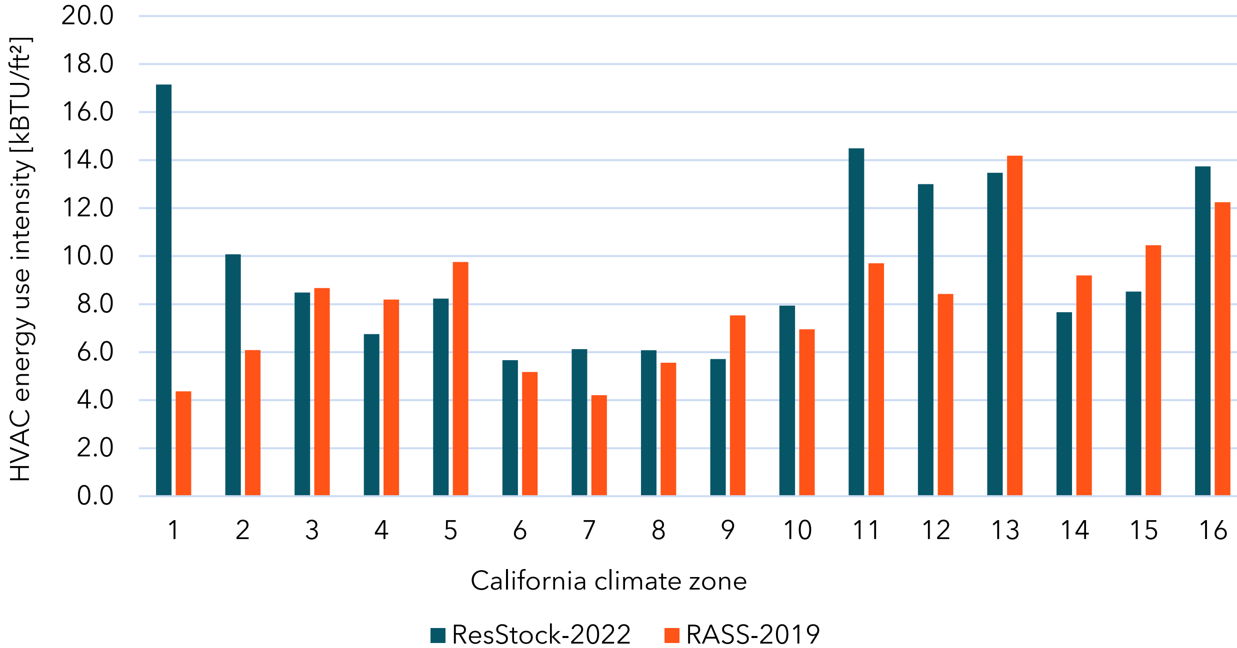
The average HVAC heating and cooling EUI by climate zone is shown in Figure 17.

Figure 17. Total HVAC EUI for multifamily by climate zone, ResStock



The DEER California-specific buildings were developed with characteristics representative of the state's existing building stock and have slight adjustments in insulation, windows, and other properties based on climate zone. The performance of the buildings is calibrated using the 2019 California Residential Appliance Saturation Survey (RASS). While these two sources of building energy usage data generally agree there are some discrepancies in climate zones 1, 2, 11, and 12, where the EUI from ResStock is higher than RASS (Figure 18). The avoided cost calculations for this report are based upon climate zone 7, 10, and 12, but we consider all climate zones for reporting energy savings and bill impacts. For the energy consumption and bill impacts reported here we use the stock DEER prototypes. More detail on the specifics of the buildings and energy modeling methodology for the avoided cost and total system benefit framework can be found in Attachment 1 of Appendix B.

Figure 18. Comparison of multifamily HVAC EUI by climate zone, ResStock and RASS



6.2 Energy consumption

Inverter driven WHPs that operate at 120V typically draw 1.5 kW of electrical power or less.[54] In contrast to 1.1 kW for 9,000 BTU/h of heating, electrical resistance heating would consume 2.6 kW. Demand response (DR) and load shifting have not been studied extensively on RHPs and similar size systems but could present a DR opportunity through integration with a central HVAC system in single-family homes, where the central system could be setback during DR events and smaller spaces conditioned with an RHP. That is beyond the scope of this study but would be an excellent research topic to explore through a future field study.

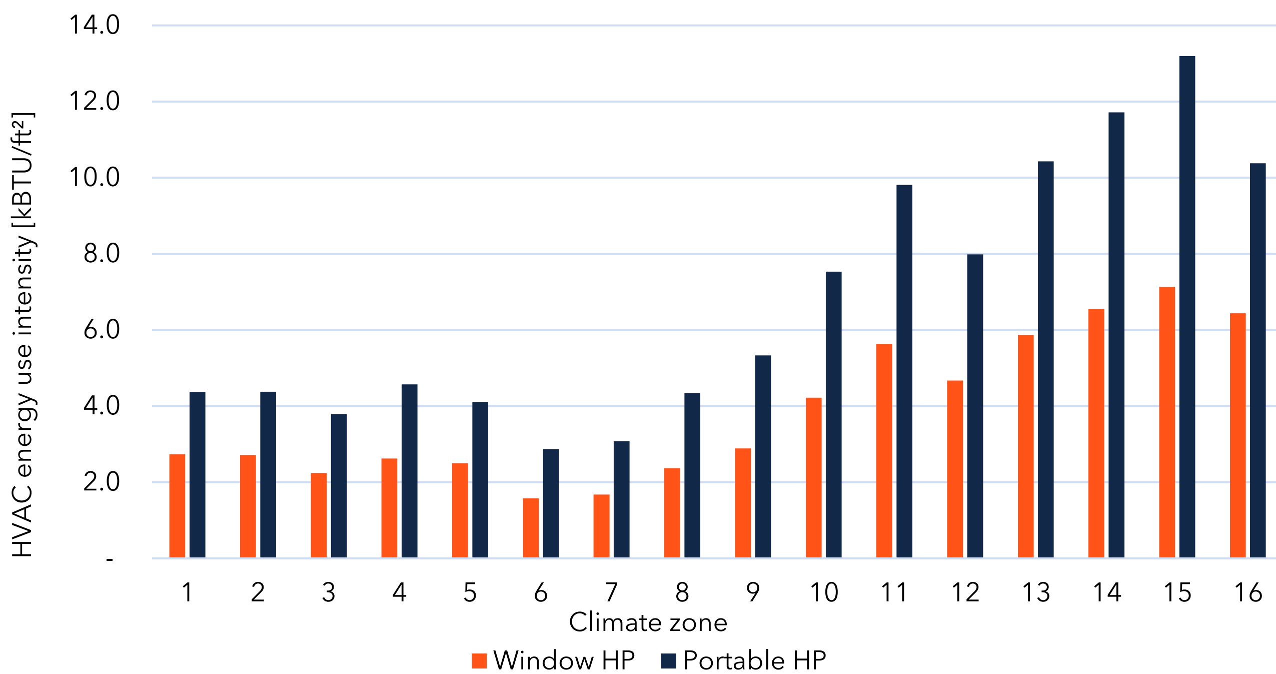
Here we focus on annual energy consumption, and later translate those results into bill impacts and avoided costs. The baseline HVAC energy for the two multifamily buildings is shown in Figure 19. As mentioned, the source of the difference in the modeled energy consumption is the data used for calibration, which causes some differences in the results. The biggest discrepancies were observed in zones 1, 2, 12, and 16 with differences of 1-2 kWh/ft^2. Without the ability to fully resolve these discrepancies, we defaulted to the California-specific DEER prototype combined with the RASS 2019 energy usage data to approximate the HVAC energy usage by climate zone in California.

[54] Using the specs from Table 1. New Type 4 Room Heat Pumps, Manufacturer Specifications, a 9,000 BTU/h heat pump operating at a COP of 2.5 (heating at 17°F) will draw 1,100 W. When cooling at 95°F with a capacity of 9,300 BTU/h and an EER of 13.6, it would draw 680W.

Figure 3, shown in the Executive Summary in Section 1, showed the comparison in annual energy consumption for three different HVAC scenarios for the multifamily building: a WHP, a window AC with electric resistance heat, and a window AC with zonal gas heat. The WHP shows significant annual energy savings compared to both other types of heating. The heat pump saves an average of 29% compared to window AC with resistance heat and an average of 55% compared to the window AC with zonal gas heat. In the second scenario with fuel substitution, there are additional considerations of energy cost and GHG emissions, but this still demonstrates the increased efficiency of heat pumps compared to incumbent technologies.

As mentioned previously, PHPs generally have lower efficiency compared with WHPs and are considered a back-up or interim technology in this MTI to solve a need of window capability currently unsolved with window units. Here we compare a PHP to a WHP across all climate zones in the multifamily building where the window unit has a 50% higher efficiency compared with the portable unit. The energy savings is consistent across all climate zones with an average of 40% savings between PHP and a WHP (Figure 19). This compares a PHP that would have the same operating characteristics as a Type 1 unit against a Type 4 WHP.

Figure 19. Comparison of portable and window heat pump EUI for multifamily building



6.3 Greenhouse gas emissions

Lifecycle GHG emissions from refrigerant

The global warming potential of a refrigerant can be a significant contributor to the lifetime GHG emissions from an HVAC system depending upon the refrigerant characteristics, the charge level in the equipment, and the amount that is released into the atmosphere. The CPUC Refrigerant Avoided Cost Calculator (RACC) estimates the leakage rates from a range of stationary equipment from as high as 24% annually for large retail refrigeration to as low as 1% annually for small sealed systems such as portable air conditioners and dehumidifiers.[55] We employ a simplified lifecycle analysis of GHG emissions and avoided costs to compare refrigerant choices and understand their impact. We examine three possible refrigerants: R-410A, R-32, and R-290. R-410A is a refrigerant currently used in many window and portable units, but that is no longer allowed in new WHPs in California due to its high GWP (GWP_{100} = 2,088 GWP_{100}-year, and 4,340 20-year), although still common in other states. R-32 is the new refrigerant of choice that meets the GWP requirements of CARB and EPA (GWP_{100} = 675, GWP_{20} = 2,330). The final choice, R-290, is propane, which is a natural refrigerant with a very low GWP (GWP_{100} = 2, GWP_{20} = 3) but is also a flammable hydrocarbon and currently only allowed in very small charge levels due to fire safety regulations.

Twenty-Year vs. 100-Year Global Warming Potential

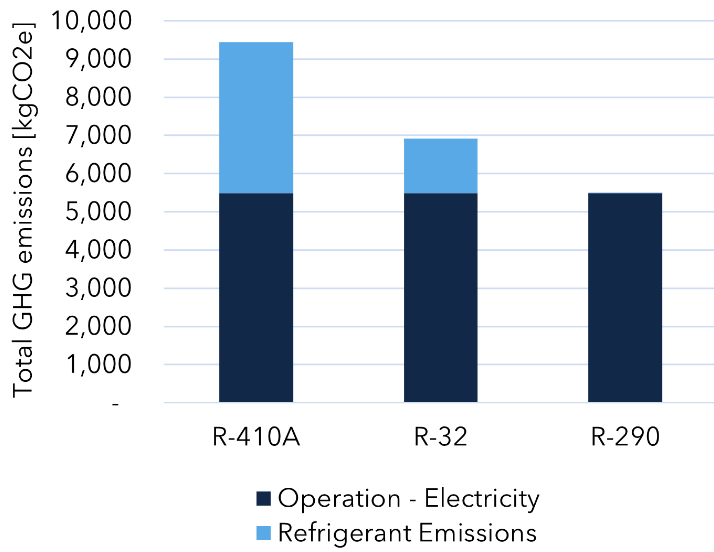
Two common GWP values used in life cycle assessment are the 20-year and 100-year GWP levels of equivalent kg of CO2. A 100-year GWP value indicates the warming effect of a refrigerant compared to carbon dioxide over a century. However, many of the molecules used as refrigerants have atmospheric lifetimes shorter than 100 years, so their warming impact is more severe in the short term. Hydrofluorocarbon (HFC) emissions can be assessed using their 20-year GWP values to gauge more immediate impacts. Typically, the average 20-year GWP is roughly three to four times the 100-year average GWP for HFCs employed in refrigeration and air conditioning equipment.[56] Most regulations, including those by the California Air Resources Board (CARB) use 100-year GWP values, although some entities, including the state of New York, have officially adopted the use of 20-year GWP values to properly capture the importance of short-lived methane and HFC emissions. Figure 20 shows the relationship between 20-year and 100-year calculations. The 100-year GWP value is aligned with general market interest in benchmarking and having common parameters for a discussion about climate change. The 20-year GWP value reflects the immediate impact of greenhouse gases on atmospheric warming.

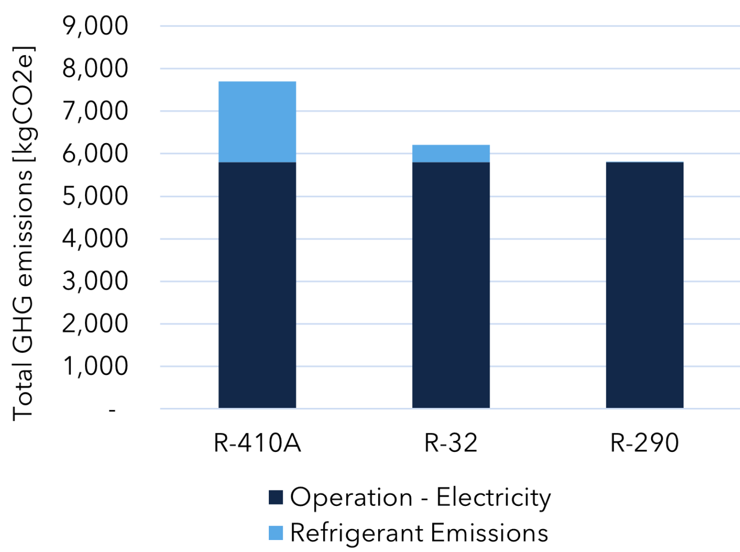
For window air conditioners, the RACC gives a 12-year device lifetime, and an annual leakage rate of 2%. However, we use the 9-year useful life from DEER, which is consistent with our other analyses. In this simplified analysis, we consider the two main sources of GHG emissions from the WHP: operational energy used for heating and cooling, and emissions of refrigerant into the atmosphere. A quick estimate of embodied carbon of the appliance, showed it to be less than 5% and is omitted for the sake of simplicity. For energy consumption we use the energy modeling of the DEER multifamily building described earlier for climate zone 10 in Riverside, which is close to the observed median energy consumption, and we use the electricity emission factors from the

[55] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-side-management/acc-models-latest-version/2022-acc-refrigerant-calculator-v1b-updated.xlsx.
[56] Atmosphere. n.d. "Refrigerants: Real GWP and PFAS." Accessed April 5, 2024. https://atmosphere.cool/fact_sheets/refrigerants-real-gwp-and-pfas/.

Avoided Cost Calculator to estimate the GHG emissions due to the electricity consumption over 9 years. For refrigerant emissions we assume the entire refrigerant charge is lost to the atmosphere at end of life. This represents the worst-case scenario as the refrigerant from some units will be recovered at end of life, but data on the reclamation rates for window air conditioners and other portable refrigeration devices are relatively limited.

Figure 20. Lifecycle GHG emissions from window heat pump, multifamily building in Sacramento, using a) 20-year refrigerant GWP b) 20-year refrigerant GWP (scenario assumes all refrigerant is emitted by EOL)





In this simplified analysis we do not account for changes in operating efficiency of the heat pumps due to refrigerant, but we do account for the required charge level of R-32 being 67% of that of R-

410A.[57] The operational GHG emissions from electricity consumption was approximately 5,800 kgCO2eq over 9 years and the GHG emissions due to refrigerant released would be 410 kgCO2eq (GWP_{100}) or 1,420 kgCO2eq (GWP_{20}) for R-32. This represents 7% or 21% of the total lifecycle GHG emissions. Using the 20-year GWP for discussion, the move from R-410A to R-32 reduces the lifecycle GHG contribution of refrigerant from 42% to 21%. Switching to propane, however, would bring the refrigerant GHG emissions down to 0.05%. Current refrigerant regulation has improved the emissions contribution, but further reductions could be achieved by the switch to natural refrigerants or robust end of life reclamation programs. The important aspect of RHPs is that these products are hermetically sealed, are not field charged, and contain a very low charge level to begin with (~2 lb. or less). While the emissions from the refrigerant should be taken seriously, the fraction of GHG emissions from refrigerant for RHPs is much lower than residential central heat pumps or commercial systems and smaller than the operational emissions from electricity consumption. This MTI could mitigate refrigerant GHG impacts through supporting the transition to natural refrigerants; however, reduction of charge levels and EOL reclamation initiatives can play a role as well if the safety regulations cannot be adjusted. The GHG savings from switching to an RHP from an electric resistance or gas heating source are substantial even with the current R32 refrigerant that is used.

6.4 Bill impacts

Energy efficiency measures using the same fuel will typically result in bill savings for consumers. Fuel substitution, however, can be more complicated due to the different in price for electricity versus natural gas. In California there is a relatively large spark gap,[58] with electricity costing 5 times or more than natural gas for the same amount of energy, based on the effective average price per kWh based upon current IOU time of use rates used in this study. Therefore, switching from electrical resistance heating to a WHP should almost certainly result in a reduction in utility bills for the user, with the amount of savings dependent upon the climate and performance of the heat pump. For our study of bill impacts, the team used present-day time of use (TOU) electricity rates published by California's three electric IOUs and Sacramento Municipal Utility District (SMUD).

Methodology

We apply the bill rates to the electricity and natural gas consumption from the energy model on an hourly basis to estimate the annual utility bills using the DEER multifamily prototype discussed in the previous section. This model has 24 units, each with 1,024 ft^2. We calculate the energy consumption and energy bills for the entire complex and then look at the average rate per unit. This accounts for changes in energy consumption due to the orientation of the building, on which level the unit resides, shading, and other details. We use three residential electricity and natural

[57] California Public Utilities Commission. 2021. "CPUC HVAC Refrigerants - Public Domain Summary." Accessed April 5, 2024.

[58] The spark gap (also known as the spark ratio) is the ratio in cost of 1 kWh of electricity to the cost of 1 kWh of natural gas. This is a common metric for assessing the economic practicality of fuel substitution.

gas rates one from each of the IOUs. We do not divide the rates by territory and apply all three across each climate zone; for bill impacts we only take the difference within the same energy rate.

The team used average per-therm cost estimates published by the three natural gas IOUs to establish baseline annual cost to operate a natural gas range in each of the four scenarios. Pacific Gas and Electric (PG&E) gas rates were used for customers in SMUD territory, and SoCalGas rates for those in Southern California Edison (SCE) territory.

For each utility territory with multiple TOU rate options, the team selected a TOU rate with no usage tiers and which included a significant differential between peak and off-peak rates, representing a trend towards TOU rates that are more reflective of wholesale power costs. Each electricity rate plan also has a fixed monthly charge ranging from $24.80 (SMUD) to $12.00 (SCE). However, the analysis assumes the customer already pays for electrical service from the utility, so the monthly charge does not factor into the incremental cost of electrifying cooking appliances and was omitted from the analysis. Monthly fixed gas service charges were not considered, since eliminating the monthly charge requires full electrification of the customer's home. However, it should be noted that customers who chose that path could save $60/year or more in fixed charges, helping to offset increases in electricity bills.

Table 6 below shows the rate plans and specific time of use rates associated with each plan, as well as annual average per-therm costs for natural gas. It is important to note that although SMUD's per-kWh rates are lower than the IOUs overall, SMUD's summer peak TOU rate is 2.5 times their summer off-peak, enabling customers to save money through load shifting. It should also be noted that customers who are eligible for California Alternate Rates for Energy (CARE) receive a discount of approximately 35% per kWh and 20% per therm, lessening the impact of electrification. Bill impacts for CARE customers, however, are not represented in the table.

Table 7. Rate plans and pricing used for billing impact analysis

PG&E Electric Home Rate Plan (Peak 4-9pm every day)	**Summer peak**	**Summer mid-peak**	**Summer off-peak**	**Winter peak**	**Winter mid-peak**	**Winter off-peak**		
Electricity rate (kWh)	$ 0.60	$ 0.44	$ 0.38	$ 0.37	$ 0.35	$ 0.33		
Natural gas rate (Therm)	$ 2.50	$ 2.50	$ 2.50	$ 2.50	$ 2.50	$ 2.50		
CARE Electricity rate (kWh	$ 0.39	$ 0.29	$ 0.25	$ 0.24	$ 0.23	$ 0.21		
CARE Natural Gas rate (Therm)	$ 2.00	$ 2.00	$ 2.00	$ 2.00	$ 2.00	$ 2.00		
SCE TOU-D Prime Rate Plan (Peak 4-9pm every day)	**Weekday summer peak**	**Weekday summer off-peak**	**Weekday winter peak**	**Weekday winter off-peak**	**Weekend summer peak**	**Weekend summer off-peak**	**Weekend winter peak**	**Weekend winter off-peak**
Electricity rate (kWh)	$ 0.61	$ 0.25	$ 0.58	$ 0.23	$ 0.38	$ 0.25	$ 0.58	$ 0.23
Natural gas rate (Therm)	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90	$ 1.90
CARE Electricity rate (kWh	$ 0.40	$ 0.16	$ 0.38	$ 0.15	$ 0.25	$ 0.16	$ 0.38	$ 0.15
CARE Natural Gas rate (Therm)	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52	$ 1.52
SDG&E TOU-ELEC Pricing Plan (Peak 4-9pm every day)	**Summer peak**	**Summer off-peak**	**Summer super-off-peak**	**Winter peak**	**Winter off-peak**	**Winter super-off-peak**		
Electricity rate (kWh)	$ 0.60	$ 0.33	$ 0.30	$ 0.60	$ 0.33	$ 0.30		
Natural gas rate (Therm)	$ 2.10	$ 2.10	$ 2.10	$ 2.10	$ 2.10	$ 2.10		
CARE Electricity rate (kWh	$ 0.39	$ 0.22	$ 0.19	$ 0.39	$ 0.22	$ 0.19		
CARE Natural Gas rate (Therm)	$ 1.68	$ 1.68	$ 1.68	$ 1.68	$ 1.68	$ 1.68		
SMUD Residential TOU Rate (Peak 5-8 pm every day)	**Summer peak**	**Summer mid-peak**	**Summer off-peak**	**Winter peak**	**Winter off-peak**			
Electricity rate (kWh)	$ 0.35	$ 0.20	$ 0.14	$ 0.16	$ 0.12			
Natural gas rate (Therm)	$ 2.50	$ 2.50	$ 2.50	$ 2.50	$ 2.50			

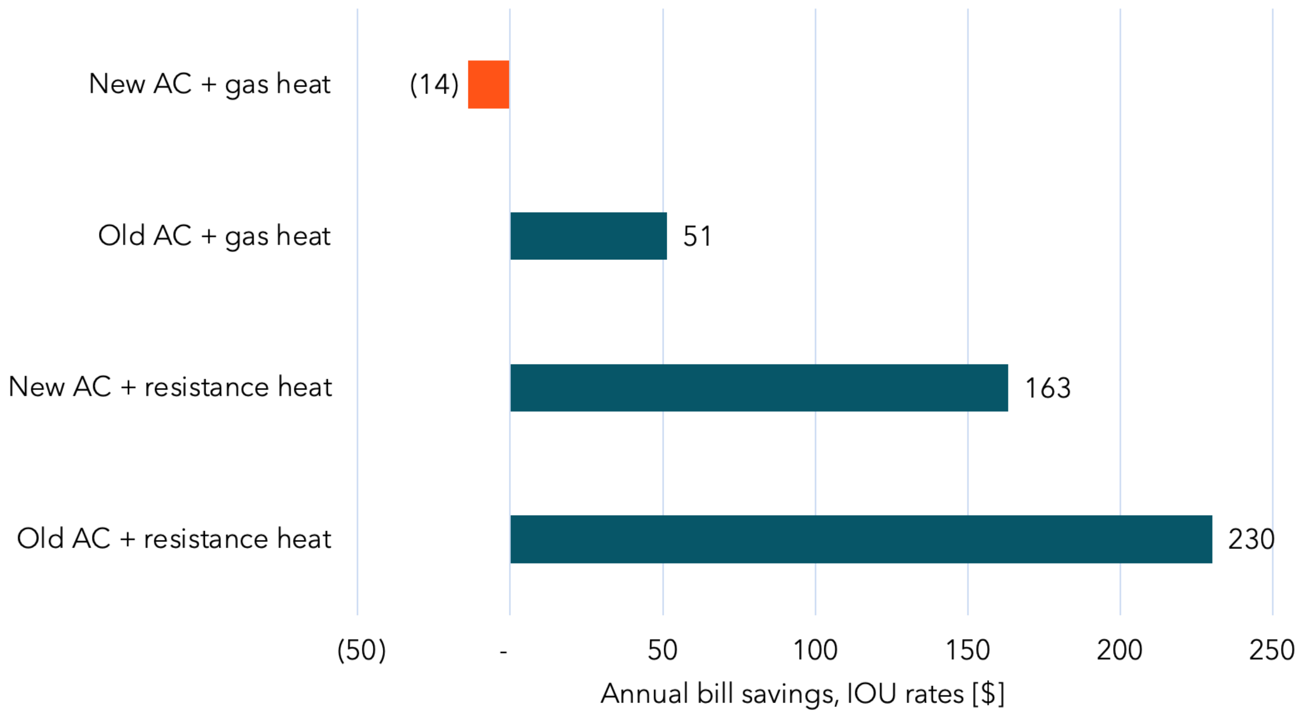
For this analysis we consider the change in utility bill costs for both new and existing HVAC types. In the avoided cost benefit analysis, we consider cases of normal replacement, where both the proposed and baseline equipment are new. The average consumer will be most sensitive to the difference in their bills before and after adding an RHP, more so than the counterfactual of what their bills might have been purchasing other new equipment. The efficiency of existing electric resistance and zonal gas heating will not be significantly less than new equipment, but the change in air conditioning efficiency is significant. For example, a 9,000 BTU/h existing window air conditioner manufactured between 2014 and 2025 meeting the minimum federal efficiency standards is 25% less efficient than one manufactured in 2026 (and also the Type 4 heat pumps from Table 1).[59] For the existing zonal HVAC equipment we use the same efficiency and specifications for heating, but reduce the cooling COP by 25% to account for the cooling savings that consumers will observe through replacing an existing window air conditioner with a WHP.

Room heat pump bill impacts - existing equipment

Figure 21 shows the average bill impacts across all climate zones for cases of electric and gas zonal heat with new and existing air conditioners in the multifamily prototype building described previously. Each data column represents the average of 3 IOU energy rates and 16 climate zones. We see that in the case of electric heating, there is significant potential for bill savings compared with both new and existing equipment. The average Californian using zonal air conditioning and electric heat would save $230 annually compared to their existing equipment and $161 compared to new equipment. For those with zonal gas heating, there is an average potential savings of $51 compared to existing equipment but an average annual bill increase of $14 compared to new equipment. This is a relatively modest amount, but more important is the range of outcomes by climate zone.

[59] The federal minimum CEER for room air conditioner without reverse cycle with louvered sides, 8,000 – 14,000 BTU/h is 12 from 2014-2025 compared to 16 starting in 2026.

Figure 21. Bill impacts comparing WHP to electric and gas heat with new and old AC



The average bill savings is greater than $50 per year in seven climate zones (8, 9, 10, 11, 13, 14, and 15) compared to existing zonal equipment. There are two climate zones with a high number of heating degree days and low cooling degree days that show bills will increase compared to both new and existing equipment (climate zones 2 and 16). These two climate zones have the largest bill increases for room heat pumps when considered against new baseline equipment as well ($39 and $103). These findings are based upon an average of 24 units from a representative multifamily building, but the specific bill impacts can vary dramatically based upon the building envelope performance, position within the building, and occupant behavior (especially thermostat setpoint). A household's current energy consumption can help predict their potential bill savings or increases due to switching to an RHP.

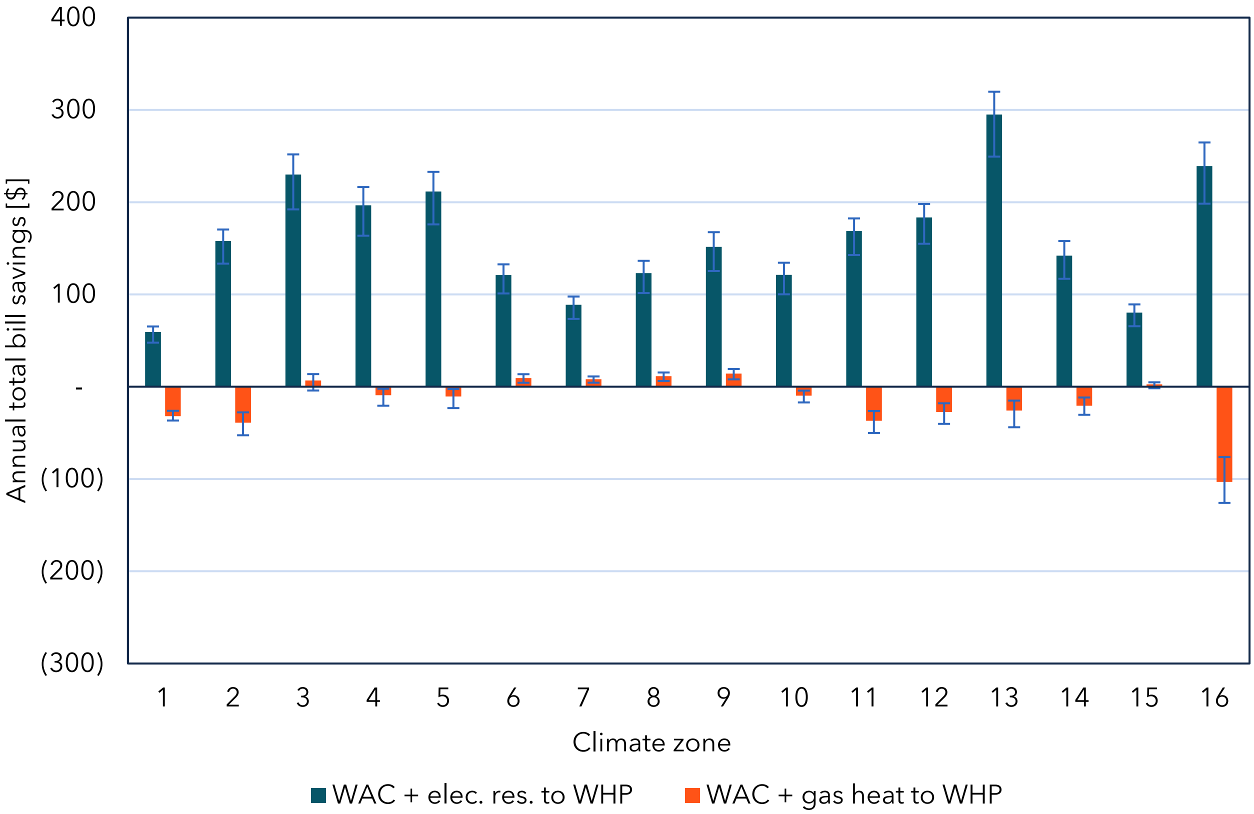
Room heat pump bill impacts - new equipment

Figure 22 shows the same bill impacts for new window AC (WAC) and zonal gas heat along with the bill impacts for new WAC and electric resistance heating. The data plotted in Figures 22 and 23 represent the average of the three rates with the error bars representing the minimum and maximum differences observed. In our modeling, we observe that in all cases there is a large predicted annual bill savings when switching to an WHP from electrical resistance heating, ranging $80 to $295 with an average annual savings of $163 (Figure 22). For fuel substitution from zonal gas heat to an WHP, 14 of the 16 climate zones indicate an increase in total energy bills, with the largest increase of $103 and an average increase of $14. Using California

Alternative Rates for Energy (CARES) rates, the maximum predicted bill increase is $23 with an average of $2 savings annually. The bill impacts for fuel-substituting with CARES rates are more advantageous because the rate reduction is between 29% and 35% for electricity and only 20% for gas, thus giving a slight improvement to electricity compared to the standard rate structure. It is important to note that the majority of the change in bill impacts will come during heating season and thus the increase in a given month could be significantly higher than taking the simple monthly average reported here. Highly efficient WHPs can offer major bill savings for customers currently using electric heating. According to the market characterization, there are 2.8M MF and 1.5M SF homes that rely primarily on electric resistance heat. The percentage of households with unducted gas heat is 11% for multifamily and 9% for single-family for a total of 1.3M households.[60] In this analysis we predict relatively small bill increases for customers currently using gas heating, but the impact on individual consumers may vary widely based upon their home vintage, local weather, and thermostat preferences. Offering more detailed bill predictions based on specific consumer scenarios may be helpful to inform consumers before they make purchasing decisions.

[60] For zonal gas heating, we use the category 'Gas, oil or wood stoves (zonal)' with the assumption that this segment is primarily natural gas and propane heating within California.

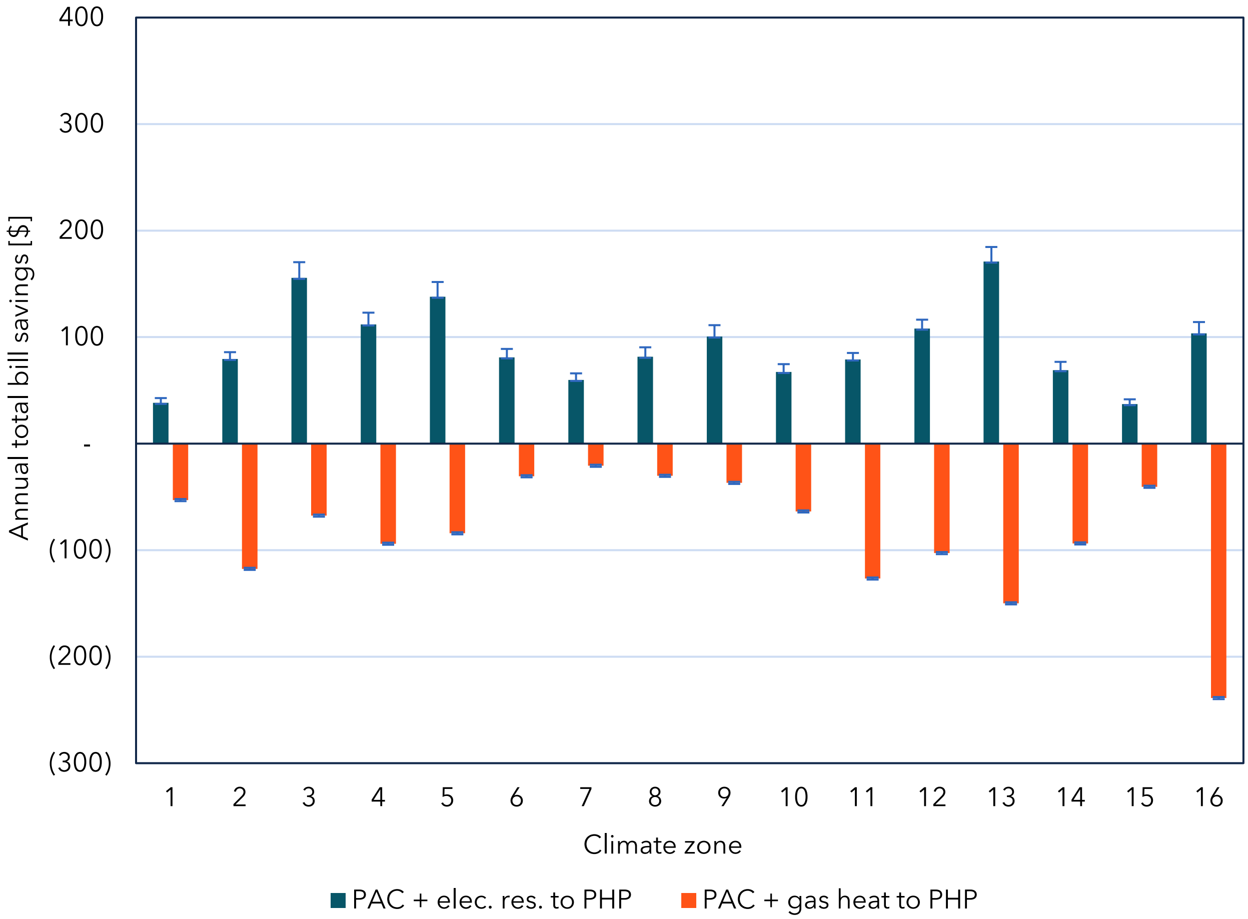
Figure 22. Annual bill impact of 1,024 ft^2 apartment, moving to WHP from window air conditioner (WAC) and electric heat (WAC + elec. res. to WHP) or window air conditioner and zonal gas heat (WAC + gas heat to WHP) for standard billing rates



Portable heat pump bill impacts - new equipment

However, the story is much different for changing over to a PHP. The lower heating efficiency of the PHP compared to the WHP increases electricity usage for space heating, which lessens the savings when changing from electrical resistance heating and creates a large, predicted bill increase when changing to a PHP from gas heating. When switching to a PHP from electrical resistance heating, that savings range from $38 to $171 with an average annual savings of $93 (Figure 23). When moving from gas heating to a PHP, the predicted bill increases are substantial: the average increase is $84 across all climate zones with climate zone 16 predicting a bill increase of $239 per year. Under the CARES rates, the average bill increase is $21 and a maximum of $68 annually. The large discrepancy in bill impacts between room and PHPs is due to the difference in heating efficiency. The effective COP of the new Type 4 saddlebag heat pumps is nearly double that of current commercially available PHPs. With the current performance level of PHPs, this product will be more effective at replacing electrical resistance heat than gas heating in most cases. A positive finding is that the CARES rate does minimize the negative bill impacts of PHPs, but there are still likely many scenarios where a household may experience unwanted bill increases if using current PHPs to replace gas heating.

Figure 23. Annual bill impact of 1,024 ft² apartment, moving to portable HP from electric heat (PAC + elec. res. to PHP) or zonal gas heat (PAC + gas heat to PHP)



Alternative rates - SMUD

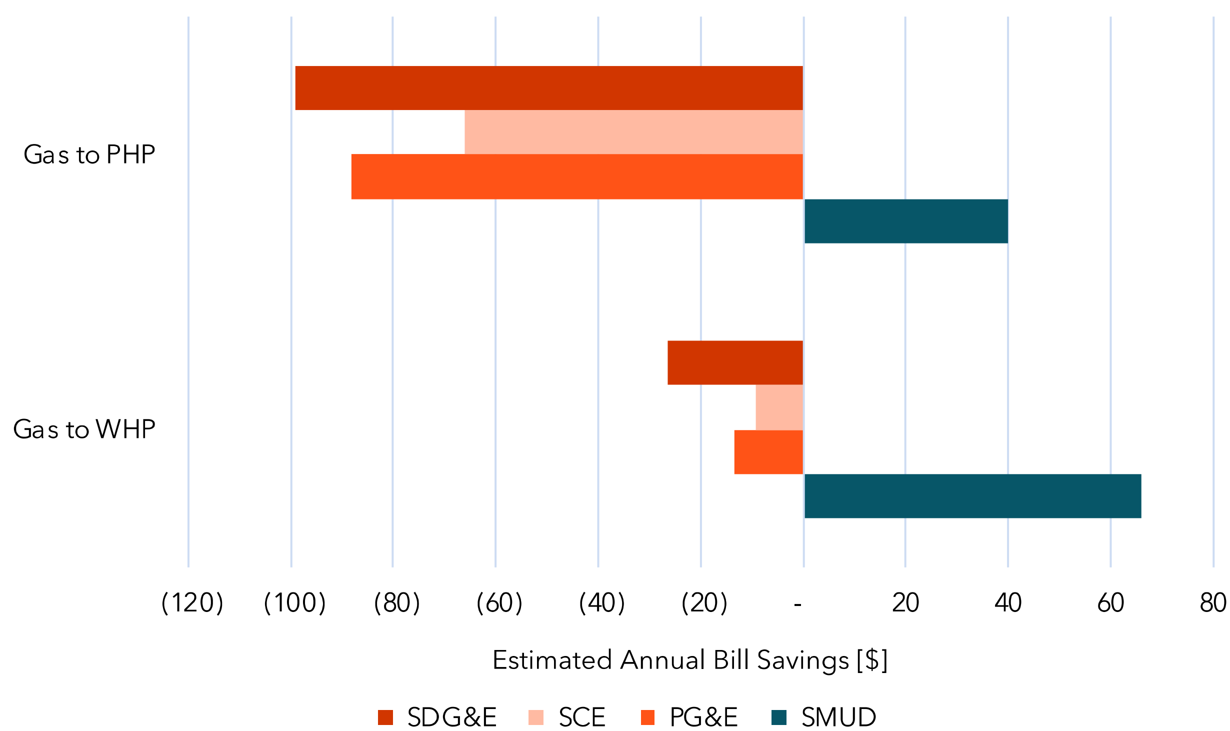
Lastly to show an example of fuel substitution in a non-IOU territory in California, we consider the SMUD rate comparing gas heating to WHPs. Rather than specifying territories, we average the energy consumption over all climate zones to minimize effects that are from weather differences rather than rates. In Figure 24 we see that the switching to either a room or PHP results in a bill savings from zonal gas heat going from an annual average bill increase of $84 to a bill savings of $40 for PHPs. For WHPs there is an average annual bill increase of $16 under IOU rates with an average bill savings of $66 under the SMUD rate.

One of the reasons SMUD can maintain relatively low per-kWh rates is by including a relatively high fixed monthly charge of $24.15, which is considerably higher than the fixed monthly charges for most IOU rate plans offered today. By shifting more cost to a fixed charge, electric utilities can support electrification by offering lower per-kWh rates, resulting in lower incremental bill impact for those moving from gas to electric appliances.

In recognition of the potential for higher fixed charges to support electrification, in May 2024 the CPUC approved an increase to the fixed monthly charge[61] in all three electric IOUs, matching SMUD's monthly charge of $24.15. When this monthly charge takes effect in late 2025 or early 2026 it should be accompanied by a reduction in per-kWh rates, reducing the cost to electrify cooking and other appliances. While any decrease will be welcomed, per-kWh IOU rates will likely remain higher than those offered by SMUD and other municipal utilities.

This finding emphasizes the need for high efficiency WHPs (like the new Type 4 products) in areas where the spark gap is high (and generally high electricity rates).

Figure 24. Comparison of fuel substitution (zonal gas heat to window or portable heat pump) for IOU rates and SMUD



[61] CPUC Energy Division AB 205 Fact Sheet, May 2024; https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-flexibility-oir/ab205_factsheet_050824.pdf.

Bill impacts – adding cooling

According to EIA RECS survey data, nearly 12% of California households do not have air conditioning. If these consumers choose to buy a heat pump, they may save energy on heating but consume additional energy through air conditioner use. We examine potential bill impacts by estimating the additional utility bills of adding an RHP compared to an existing multifamily household that has no AC and uses either zonal electric or gas heat. We observe that climate zones 1-6 can still achieve bill savings when switching from no cooling and electric heat (an average of $112) but would pay an average of $67 more if changing from zonal gas heat. Climate zones 7 – 9 have small bill increases for electric heat ($16 average) but relatively large for zonal gas heat ($127 average). Other climate zones have high enough cooling degree days that a no cooling baseline was not considered.

6.5 Product reliability

WHPs that plug into 120V outlet are a relatively new type of appliance, especially with the colder climate versions that are just hitting the market for the first time in 2024. This limits the available information on product reliability with much of it being anecdotal. It is likely in the first few years of deployment of cold-climate WHPs there will be some reliability issues as manufacturers deploy these new active defrost and condensation management systems. However, if managed properly with customer service and warranties, this is unlikely to be a significant issue for the adoption of WHPs broadly. Residential split heat pumps may offer some insight into the future reliability of WHPs. Consumer Reports surveyed 10,000 customers with air source heat pumps installed between 2007 and 2023 and found that roughly half of all units experienced a problem within the first eight years, making it one of the least reliable appliances analyzed by CR.[62] RHP product reliability is still unknown, but the possibility of poor reliability is a risk that should be monitored throughout the MTI, because it can not only create poor customer satisfaction but also dangerous situations if users are left without working heat during extreme cold events.

6.6 Technical supply chain considerations

Currently, there are only two types of RHP products on the market: legacy Type 1 heat pumps and new saddlebag Type 4 heat pumps. There is adequate availability of Type 1 RHPs for consumers who want a low-cost option that will supplement other heating sources. For consumers interested in using an RHP as the sole source of heating, there are only two Type 4 WHPs, and both are slated for release late in 2024. One of the heat pumps is manufactured by Midea, a large multi-national corporation with a wide product line of HVAC appliances, that is capable of manufacturing at scale. Midea is headquartered in China, with manufacturing facilities in China and 16 other countries worldwide.[63] The other company, Gradient is a start-up based in San Francisco that was founded in 2017 with the intent of creating consumer heat pump products.

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[62] https://www.consumerreports.org/appliances/heat-pumps/most-and-least-reliable-heat-pumps-a2741062924/.
[63] https://www.midea-group.com/about-us/manufacturing.

Gradient has created innovative products but will still need to demonstrate the ability to scale manufacturing to meet potential demand in California and across the US.

For a well-functioning marketplace, CalMTA would like to engage additional manufacturers to develop WHP products, expanding the availability of different products to achieve a diversity of performance, cost, form-factor, and features so that consumers can choose the products that best fit them, and for costs of the high-performance Type 4 heat pumps come down with time. There are several major manufacturers of window AC, packaged terminal heat pumps and air conditioners, and other small HVAC appliances who could potentially develop competitive products if there was enough market demand as there is currently with window air conditioners.

7 Product plan

7.1 Objectives

Short-term objectives

In the short term (1-3 years), the MTI will seek to engage manufacturers on two issues:

- Creating product solutions for horizontal slider and casement windows
- Optimizing heat pumps with the right cost/temperature performance for California climate

Getting heat pump products that can fit into vertical windows is a high priority for the MTI because these window types are currently limited to PHPs, which have lower efficiency and poor low temperature performance with hoses that are unappealing to many consumers. The high proportion of residential buildings with slider and casement windows was discovered during the current MTI phase through an installation pilot as well as a consumer survey. The lack of consumer satisfaction with the appearance of PHPs was also reported in the consumer insights study in the market characterization research. [64]

In terms of better temperature performance, the two new Type 4 heat pumps being released in 2024 are a major step forward in the performance of WHPs with impressive efficiency and low temperature heating capacity. However, the heating performance significantly exceeds what is needed for most of California, and the corresponding high cost may limit adoption and be a very serious barrier in ESJ communities. Products meeting the Type 2 and Type 3 definition of the EPA RHP test procedure (rather than the more extreme Type 4) will provide a better balance of price and performance for California consumers. Incentivizing manufacturers by creating a specification and aggregating housing authorities to guarantee orders may help open the market for these mid-level performance WHPs.

[64] See Appendix D: Market Characterization Report for Room Heat Pumps.

Long-term objectives

Longer-term product technical challenges include:

- Creating products with high efficiency air filtration capabilities
- Creating products with outdoor air ventilation options (including energy recovery ventilation)
- Reducing the total GWP of refrigerant per heat pump

A key long-term priority is creating solutions to improve indoor air quality through options such as integrated high-efficiency air filtration, the type mentioned earlier for the Friedreich Kuhl line of air conditioners. High-efficiency air filtration creates challenges with pressure drop requiring increased fan capacity and decreasing the energy efficiency of the product. Additionally, the filter media increases the size of the device, and the replaceable filters can be a sizable operating expense when replaced at regular intervals. Creating cost effective and energy efficient solutions for air filtration in WHPs will likely be a slow process, and therefore the MTI team wants to engage early with manufacturers to explore options.

The long-term objectives are high priority but anticipated to take longer time periods through work with manufacturers or regulations. The use of natural refrigerants may take significant work to adjust building safety regulations, while the product developments to integrate energy recovery ventilation and air filtration are different enough from current products. Thus, we believe this will be a long-term engagement, as further discussed in the subsequent section.

7.2 Product plan actions

Technology Actions

Understanding user behavior and energy savings from WHP as secondary HVAC source

Approximately 6 million single-family homes in California use a ducted gas furnace as the primary heating source. This market represents a huge potential for displacement savings from adding a WHP as a secondary heating and cooling source. There are many situations where a large (>2,500 ft^2) house only needs one or two rooms (~500 ft^2) conditioned for extended periods of time, either while working from an office during the day or sleeping in a single bedroom at night. If implemented properly, setting back the central HVAC for 8 hours and conditioning a single space with an efficient heat pump could provide significant benefits in reduction of natural gas consumption during the winter and electrical and consumption during the summer. However, the level of savings achieved is currently heavily dependent upon the occupant properly configuring the thermostats of both HVAC systems. If the system controls are not optimized, it's very possible that more energy will be consumed by adding supplemental space conditioning. A field study would help assess occupant behavior and identify strategies to improve energy savings. Additionally, the study could test the integration of smart controls that allowed the systems to interact and optimized savings with less user input, with A/B testing to compare the savings of users with manual control of their RHP thermostats and those with integrated smart controls. If the two HVAC systems are integrated, this could also increase the opportunity for demand response with larger setbacks for the main system during a DR event.

Investigating pathways to reduce the GWP of the refrigerant in window heat pumps

The total GWP of refrigerant in a WHP depends upon the amount of refrigerant and also the specific GWP of refrigerant used (in kgCO2 per kg of refrigerant). Reducing either of these can reduce the potential GWP impact of a product and reducing leakage rates and improving end of life recovery are all ways to mitigate the GWP emissions of the product. We recommend the MTI take a wholistic approach when looking at refrigerant GHG mitigation. Since WHPs are hermitically sealed in the factory and not field serviced, leakage is not typically a major source of emissions. End of life recovery can be an area of focus that is well within the purview of the MTI but is not one of the technical challenges. Reducing the amount of refrigerant in each unit can benefit GHG mitigation in two ways: it can reduce the amount that can be released with improper disposal, but it can also lower the amount of flammable refrigerant to comply with relevant current or future building codes. R-32 is designated as A2L or somewhat flammable, while propane is designated as A3, highly flammable. The charge limits have recently been expanded to allow A2L refrigerants in residential HVAC, but the maximum amount of A3 refrigerant allowed in an application such as RHP is 114 g, which is below the typical charge level required. However, recent advancements have created systems that can both use less refrigerant and utilize it in a safer manner. For example, the Gradient heat pump using hydronic coupling to the inner coils so that the refrigerant is all contained in the outside unit and does not cross into the living space. Ephoca also recently did trial of micro heat pumps installed in Europe using propane and redesigned the system to use only 150 g of refrigerant and embed leak detection sensors.[65] Clearly there is room for new product innovation but also more research on safe flammability limits for A3. A 2017 research study[66] commissioned by ASHRAE indicated that the safe level of A3 refrigerants was very dependent upon the size of space and that 150 g was safe for retail store areas of 405 ft^2 and that 300 g would be safe for a deli of 1,000 ft^2 but further modeling and experimental research would be needed to understand safe limits in living areas, or for the external coils outside of a window.

Product development actions

Development of a product for narrow window openings

Several primary goals exist for product development of WHP products throughout the MTI. The most significant need is for WHP products that can work in casement and slider windows that are prevalent across California. There are several paths by which this could be accomplished: 1) development of a WHP with a vertical form factor, capable of fitting into the narrow window style; 2) development of a PHP with higher efficiency and more elegant integration into the window

[65] https://www.lifezerogwp.eu/project-results/.

[66] https://www.nfpa.org/education-and-research/research/fire-protection-research-foundation/projects-and-reports/evaluation-of-the-fire-hazrd-of-ashrae-cass-a3-refigerants-in-commercial-refrigeration-applications.

opening; 3) creating new a new product configuration that is able to operate as an efficient heat pump with active defrost while utilizing a narrow window opening to transfer heat to and from the outside. Currently, there are casement window air conditioner products specifically designed to fit more narrow openings, with a typical width of approximately 16'' or less. An example of a casement window air conditioner is shown below in Figure 25. This unit is 15'' wide, 21'' tall, and 24'' deep and has a cooling capacity of 10,000 BTU/h.[67] New products to meet this need might not look like typical casement window air conditioners, but this product demonstrates the feasibility of creating a new form factor. There are additional complexities in upsizing units to provide heating functionality at lower temperatures, but the details of that remain to be seen, especially due to the lack of available Type 2 and Type 3 RHPs currently on the market.

[67] https://www.homedepot.com/p/Midea-10-000-BTU-115V-Window-Air-Conditioner-Cools-450-Sq-Ft-with-Remote-Control-in-Gray-KAW10C1AWT/312731023.

Figure 25. Casement window air conditioner designed for narrow openings

The second option would be for the development of higher performance PHPs that are capable of providing heating down to 17°F. Manufacturers currently have heat pumps in this form factor, but the challenges of increasing the coil size, implementing active defrost, and meltwater management in the portable form factor could prove more challenging than a vertical WHP. If this MTI were to develop a challenge specification, it would be advantageous to set it up in a way to allow either option to qualify, as long as the performance metrics were met.

Codes development actions

This section lays out the activities undertaken in the short (1-3 year) and long (4-10 years) term related to development of code, standard, and/or test procedures in Table 8.

Table 8. Code development actions

Category	Barriers	Opportunities
Codes & Standards	Currently no federal standard on heating efficiency	Align with CA-based stakeholders and other groups with similar product needs to support rule-making process
Codes & Standards	Complexity of different CEER metrics for portable and room air conditioning categories	Support efforts to include PHPs in EPA RHP procedure
Product Performance	Current products have no standard for reporting heating performance	Create qualified products list that requires use of the voluntary EPA RHP test
Product Performance	No window style units available for casement or slider windows	Create CA heat pump specification
Product Performance	Limited products that have IAQ benefits (ventilation and filtration)	Engage with manufacturers to create integrated filtration product options
Product Performance	All available products use refrigerant GWP > 600	Look towards experiences in Europe for guidance
Product Performance	No products currently provide adequate heating and a price competitive with competing non-HP technologies	Campaign to inform consumers of bill savings compared with other electrical heating
Product Availability	Limited availability of Type 2, 3, and 4 models	Leverage housing authorities to purchase new products to increase demand
Product Availability	Limited availability of HP in saddlebag and U-shaped form factors	Leverage housing authorities to purchase new products to increase demand
Product Reliability	Currently unknown for all weather products	Monitor reliability data as market matures
Category	**Activities**	
	1-3 Years	**4-10 Years**
Codes & Standards	Follow and support EPA and DOE test methods for heating, encourage inclusion of portable units	Support studies around the safe use of natural refrigerants
Product Performance	Create CA RHP challenge specs for vertical HP and Type 2 and 3 products. Start work towards air filtration units.	Create incentives for manufacturers related to developing RHPs with ventilation.
Product Availability	Create incentives for additional manufacturers to develop U-shaped and saddlebag Type 2 & 3 heat pumps	

8 Technical potential

According to the DOE, "Technical Potential is the total energy that could be saved by efficiency measures, without consideration of cost or willingness of users to adopt the measure."[68] Although CalMTA did not perform a formal technical potential study, the team used market segmentation and avoided cost data developed for TSB calculations to create an estimate of total technical potential. In this analysis, we consider the instantaneous technical potential, which is the theoretical maximum savings from converting all equipment to the highest efficiency level of the MTI products.[69]

8.1 Technical/Market baseline

The technical potential for RHPs is calculated based on the total available market in California residential buildings and expected useful life of the proposed appliance. It does not account for changes in the market over time, baseline market adoption for the target technology, or other market factors—it is simply the maximum potential impact of the technology if it were adopted in 100% of California homes and apartments that are identified as part of the target market in 2024. Replacement cases consider all California households with zonal heating and cooling as well as multifamily households with central HVAC systems, excluding those that currently use heat pumps. The displacement cases consider California single-family households with ducted central HVAC systems, including those with heat pumps. A separate case is considered for households adding cooling that previously had none. Households that currently have no heating or cooling are excluded from the total available market. The total available market includes more than 4.0M multifamily households and 8.8M single-family households for a total of 12.8M. The market segmentation is described in more detail in the documentation for total system benefit estimates.[70]

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[68] U.S. Department of Energy, *Energy Efficiency Potential Studies Catalog*, accessed July 7, 2024, https://www.energy.gov/scep/slsc/energy-efficiency-potential-studies-catalog#:~:text=Technical%20potential%20is%20the%20total%20energy%20that%20could,a%20supply-side%20energy%20resource%20alternative%20%28i.e.%2C%20energy%20generation%29.

[69] 2025 Potential and Goals Study Draft Workplan, CPUC Report, Reference No.: 221115. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/energy-efficiency/2025-potential-goals-study/draft-2025-pg-study-work-plan.pdf.

[70] See MTI Plan Appendix B: Market Forecasting & Cost Effectiveness Modeling Approach.

8.2 Unit energy savings and avoided costs

The CPUC's Avoided Cost Calculator (ACC[71]) provides a robust framework for evaluating the impact of fuel substitution measures, like electrification of space heating. Since the calculator estimates the impacts of gas and electricity consumption to dollars of avoided cost, it provides a metric to calculate the impact of both fuel substitution measures as well as pure efficiency measures. The ACC estimates system-level costs of providing electric or gas service on an hourly basis in $/kWh and $/therm.[72] The calculator is comprised of three parts: an electric avoided cost calculator, a natural gas avoided cost calculator, and a refrigerant calculator. Since the calculator covers gas and electricity consumption to dollars of avoided cost, it provides a metric to calculate the impact of fuel substitution measures and pure efficiency measures technology value from the baseline value to calculate the avoided costs for how much money is saved in the electrical grid and associate emissions through the adoption of one unit. The avoided cost factors (in $/kWh and $/therm) are applied to a unit energy savings shape on an hourly basis to calculate the avoided cost benefit per scenario, which is an input for the estimate of the MTIs cost effectiveness and total system benefit (TSB).

We batch the avoided cost factors into three categories: energy benefits, grid benefits, and greenhouse gas benefits, which are the categories that are used for TSB reporting in this work. Table 9 lists the ACC workbook factors from the electric and gas models and how they are grouped in the three categories for reporting.

Table 9. ACC factors by category

	Electric model	**Gas model**
Energy	Energy	Market (commodity)
Grid	Generation capacity	Transmission and distribution
	Transmission capacity	
	Distribution capacity	
	Ancillary Services	
	Losses	

[71] Per the CPUC, "The primary benefits of demand-side resources are the avoided costs related to generation and distribution of energy. The avoided costs of electricity are modeled based on the following components: generation energy, generation capacity, ancillary services, transmission and distribution capacity, and decarbonization policy compliance. The Avoided Cost Calculator was established in 2005 and is updated biennially to improve the accuracy of how the benefits of demand-side resources are calculated."

[72] 2024 Distributed Energy Resources Avoided Cost Calculator Documentation. https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-side-management/acc-models-latest-version/2024-acc-documentation-v1b.pdf.

	Electric model	Gas model
GHG	Cap and trade	Environment (CO2 and NOx emissions)
	GHG adder	Upstream methane leakage
	GHG rebalancing	Behind-the-meter methane leakage
	Methane leakage	Gas air quality adder
	Air quality adder	N/A

As mentioned in the methodology section, the team used EnergyPlus to model single-family and multifamily prototypes, which were modified to represent existing single-family and multifamily building envelope features. Baseline conditioning systems included window ACs with electric resistance heaters, window ACs with zonal gas heating, and portable ACs combined with the same two baseline heating sources. The proposed design models included WHPs and PHPs to provide both heating and cooling. Here we report the avoided cost benefits across all 16 climate zones, although only one climate zone per IOU is used in the TSB estimates reported in a separate appendix.[73] For all cases that include cooling, energy modeling was performed for California climate zones 7, 10, and 12. For the cases with no existing cooling the modeling was performed in climate zones 3, 6, and 7. The normal replacement cases involve a one to one replacement of the baseline equipment with the proposed equipment and applies to both multifamily and single-family homes without central ducted HVAC. The displacement case covers the usage of room and PHPs in one zone of a larger single-family home with thermostat setbacks. More details on the case descriptions, energy modeling, and avoided cost calculations can be found in the attachment to this report.

There are 14 different savings cases identified with different combinations of baseline and proposed equipment and building types (Table 10). Each of these cases is applied across three climate zones (one per IOU) generating 42 unique unit energy savings (UES) and avoided cost scenarios.

Table 10. UES case descriptions

Case	Savings shape[74]	Climate zones	Segment	Proposed equipment type	Baseline equipment type
1	1, 2, 3	7, 10, 12	MF	WHP	WAC + elec. res. heat
2	4, 5, 6	7, 10, 12	MF	WHP	WAC + zonal gas heat
3	7, 8, 9	7, 10, 12	MF	PHP	PAC + elec. res. heat
4	10, 11, 12	7, 10, 12	MF	PHP	PAC + zonal gas heat
5	13, 14, 15	7, 10, 12	SF	WHP	WAC + elec. res. heat

[73] Please refer to the attachment in this appendix for more information on UES development and the separate appendix on TSB calculations for more information on how the avoided cost values are used in the model.

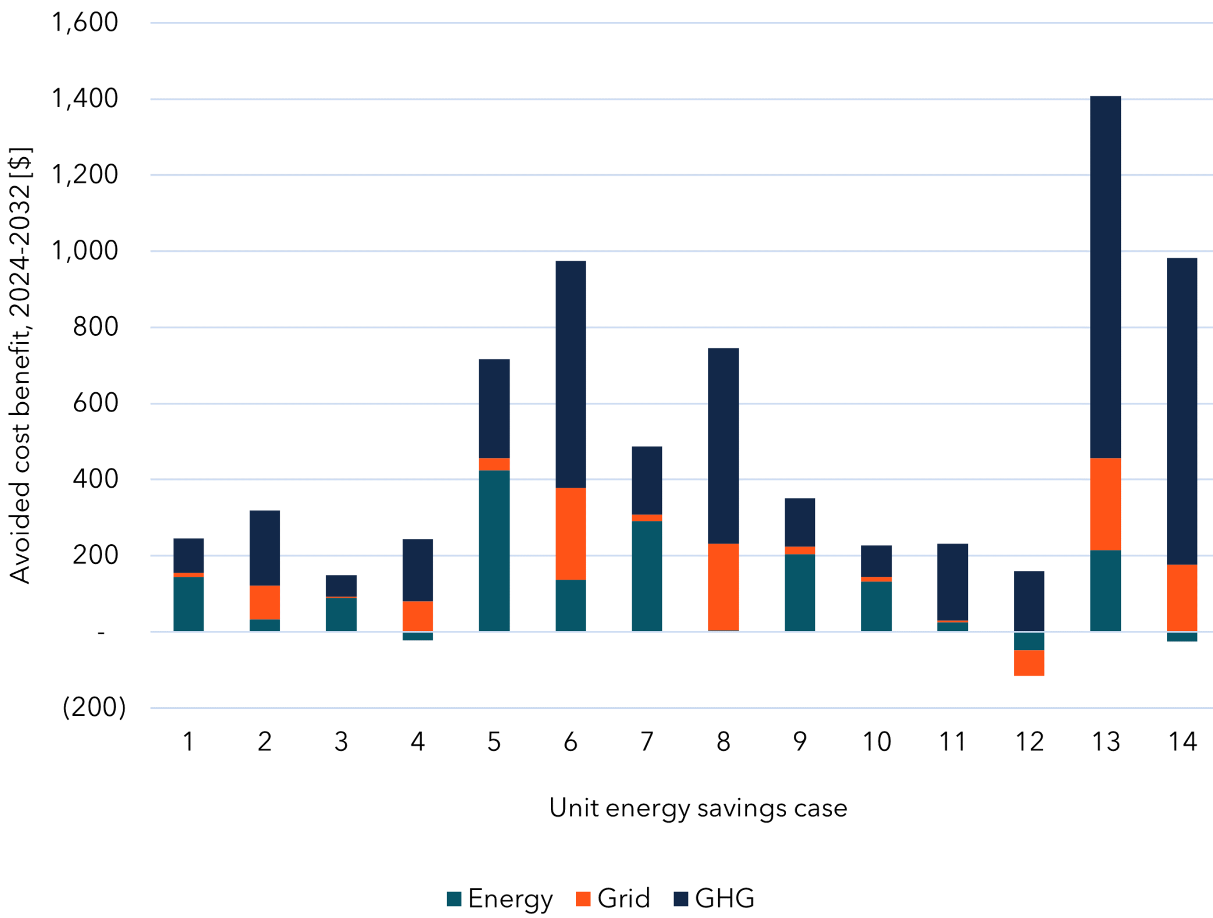
[74] The savings shape is dependent upon the weather for an individual case (one building type, one proposed and baseline equipment combination) there will be three savings shapes generated, one for each climate zone.

Case	Savings shape[74]	Climate zones	Segment	Proposed equipment type	Baseline equipment type
6	16, 17, 18	7, 10, 12	SF	WHP	WAC + zonal gas heat
7	19, 20, 21	7, 10, 12	SF	PHP	PAC + elec. res. heat
8	22, 23, 24	7, 10, 12	SF	PHP	PAC + zonal gas heat
9	25, 26, 27	7, 10, 12	SF	WHP	WAC + elec. res. heat
10	28, 29, 30	7, 10, 12	SF	PHP	PAC + elec. res. heat
11	31, 32, 33	7, 6, 3	MF	WHP	NC + central GF
12	34, 35, 36	7, 6, 3	MF	PHP	NC + central GF
13	37, 38, 39	7, 6, 3	SF	WHP	NC + central GF
14	40, 41, 42	7, 6, 3	SF	PHP	NC + central GF

Abbreviations used in the table: Res = Residential, MF = multifamily, SF = single-family, NR = normal replacement, Disp. = displacement, WHP = window heat pump, PHP = portable heat pump, WAC = window air conditioner, PAC = portable air conditioner, elec. res. = electrical resistance, NC = no cooling, GF = gas furnace.

The avoided cost benefit for each case from Table 10 was calculated based upon a start date of 2024 and extending through the estimated useful life of the appliance, 2032. The avoided costs of both the proposed and baseline cases were calculated on an hourly basis for 9 years and were converted into 2024 dollars using the discount rate from the ACC workbook, 7.3%. The avoided cost benefit is the difference between the baseline and proposed case. The avoided cost benefit for each UES case is shown in Figure 26, broken down by the energy, grid, and GHG benefits. The avoided cost benefits for normal replacement cases range from $148 to $318 for multifamily and $487 to $975 for single-family. The increased avoided cost benefit for single-family is partially due to the higher load per area of the small single-family and partially due to the larger conditioned zone in the single-family home (512 versus 727 ft^2). For the replacement cases, the PHPs provided an avoided cost benefit that was an average of 31% lower compared to RHPs. The displacement cases for using a heat pump in a single zone of a large single family generally had a similar avoided cost benefit compared to normal replacement in multifamily. Single-family homes with central heating and cooling represent the largest segment of households at 39%. The no cooling cases had relatively low avoided cost benefit for multi-family ($244 for RHP and $44 for PHP), but a very high avoided cost benefit for single-family ($1,408 for RHP and $958 for PHP). This is because the baseline scenario includes an existing central gas furnace, which is less efficient than a new gas wall furnace when considering fan power and total system efficiency. The cooling loads in climate zones 3, 6, and 7 are relatively low for both single and multifamily minimizing the negative effect of adding cooling energy, and the heating loads in the single-family homes are much larger than compared with the multifamily. Single-family homes with central gas heating and no cooling represent 9.7% of households in California, but it is unclear how likely this population would be to add a heat pump for cooling, when they already have central heating.

Figure 26. Avoided cost benefit by UES case, 2024-2032



8.3 Total technical potential results

For the technical potential estimate, we average avoided cost benefit for all 3 IOUs per case and apply that to the statewide available market. Table 11 lists the estimate of total technical potential for RHPs in California. Because this analysis only considers the use of the most efficient proposed technology, the avoided cost benefits from RHPs (as opposed to PHPs) are used in each market segment. The total technical potential is $6.6B with 16% in multifamily and 84% in single-family. The avoided cost benefit for single family is much higher due to the large number of single-family homes available for the displacement case (5.15M), as well as the high avoided cost benefit per unit of supplanting existing central gas furnace heating with a heat pump (in case 13). The technical potential does not address the likelihood of households in either of these segments to adopt RHP in contrast to cases in multifamily and small single-family where RHPs can directly replace other HVAC types (cases 1, 2, 5, 6). This will all be accounted for in the market adoption predictions that inform the TSB.

This analysis estimates the benefit in full adoption in the first year of the program. The avoided cost benefits for both energy efficiency and fuel substitution grow each year in nominal dollars, but due to the discount rate of 7.3% used for the total resource cost (TRC) in the ACC, the highest avoided cost for each scenario is in the first year of the program when considering the net present value.

Table 11. Total technical potential for room heat pumps in California

Case	Segment	Decision Type	Proposed Equipment Type	Baseline Equipment Type	Avoided cost benefit	Total units [k]	Avoided cost [M]
1	MF	NR	RHP	Room AC + Electric Resistance Heat	$ 245	2,756	$ 676
2	MF	NR	RHP	Room AC + Zonal Gas Heat	$ 318	1,025	$ 326
5	SF	NR	RHP	Room AC + Electric Resistance Heat	$ 717	1,506	$ 1,079
6	SF	NR	RHP	Room AC + Zonal Gas Heat	$ 975	788	$ 769
9	SF	Disp.	RHP	Room AC + Electric Resistance Heat	$ 351	5,155	$ 1,808
10	MF	TBD	RHP	No Cooling + Central Gas Furnace	$ 226	248	$ 56
13	SF	TBD	RHP	No Cooling + Central Gas Furnace	$ 1,408	1,345	$ 1,894
					Total	**12,823**	**6,608**

9 Risk Assessment

9.1 No new products become available for slider and casement windows

There is a real possibility that manufacturers will be reluctant to create new form factor products in an immature market where the normal form factors have yet to reach high volume. Additionally, casement window air conditioners have existed for some time and never become popular in part due to the solution being clunky and unsightly. One option to circumvent this issue is to engage manufacturers of PHPs to create higher performance portable products with improved aesthetics. There are some challenges with the size and form factor of PHPs that may prevent Type 4 (cold climate) versions, but there may be opportunities to create PHPs that can operate down to ~25°F and satisfy a large portion of the market. The other option could be to look toward systems with small external ducts through the wall such as Ephoca. This may take some small work from a contractor but may be a viable option for large scale installation in multifamily buildings. It is preferrable to avoid building modifications wherever possible, but this could be a backup strategy if the MTI is unable to effectively enable new room or PHPs to meet this market need.

9.2 No Type 2 & 3 heat pumps are developed

In this scenario, the market remains bifurcated with currently available mild climate (ENERGY STAR RHP, Type 1) heat pumps and the newly released cold climate (Type 4) models. It is possible that the market shift towards less expensive ductless mini-splits may drive down the price of the cold climate WHPs as well. If not, the MTI should look to expand collaboration with housing authorities and efficiency organizations across the warmer portions of the US to create a larger product challenge with incentives sufficient to engage manufacturers.

9.3 Natural flammable refrigerants such as propane are never allowed to be used in window heat pumps

It is quite possible that the current charge limits on A3 refrigerants remain in place for many years to come, creating a barrier to a possible low-GWP refrigerant. As mentioned previously, the GHG impact of refrigerants can still be mitigated through reduction in charge levels and programs to ensure proper end of life recovery thus maintaining a low GHG impact without switching refrigerants.

9.4 Manufacturers will not create products that have integrated air filtration

The market demand for RHPs with air filtration is not yet established and manufacturers may be hesitant to undergo new product development for this feature with so many other competing priorities. Without products with integrated air filtration, the indoor air quality of many consumers, especially in small multifamily homes may be negatively impacted. One possible solution to this problem is to create interventions pairing WHPs with portable HEPA filters.

Attachment: Unit Energy Savings & Avoided Cost Calculation Methodology

See Appendix B: Market Forecasting and Cost-Effectiveness Modeling Approach for this attachment.