Consumers Energy All-Electric Multifamily Design Guide

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Consumers Energy
Count on Us®

Contributing Authors

Redwood Energy: Sean Armstrong, Emily Higbee

Consumers Energy: Umay Akkoseoglu, Ben Glendening, Celia Hoag, Annie Koch, Douglas Kot, Melissa Kelley

Contact

Business Pilot Services, Consumers Energy
(877) 607-0737
ConsumersEnergyBusinessSolutions@cmsenergy.com

Sean Armstrong, Redwood Energy
(707) 826-1450
sean@redwoodenergy.net

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Introduction

In June 2021, Consumers Energy published an update to the Clean Energy Plan[1] to better serve the people, planet, and Michigan's prosperity over the next twenty years. The plan outlines a detailed strategy to meet their business owner's long-term needs by identifying the following goals to be achieved:

- Be one of the first utilities in the nation to go coal-free by 2025;
- Stay on the path to achieve net zero carbon emissions (~60% carbon emissions reduction by 2025), and
- Build nearly 8,000 megawatts of solar energy to power Michigan's homes and businesses by 2040.

Consumers Energy's Zero Net Energy Companion Program was developed to assist new construction business owners in achieving ZNE and all-electric goals with the overarching mission of reducing dependency on greenhouse gases in alignment with the Clean Energy Plan's goals.

The purpose of this design guide is to be used as an accompanying handbook to Consumers Energy's ZNE Program and to promote market transformation through the education of building owners, developers, designers, and contractors on the financial, health and environmental benefits of building all-electric multifamily housing in Michigan. A Case Studies section is included to illustrate best practices, and an all-electric product guide of appliances can be referenced to substitute natural gas fueled systems in a multifamily development.

Objectives

This design guideline is intended to be used as a reference for building owners and their design teams seeking to achieve an all-electric, zero net energy multifamily project. The guideline provides a pathway for Consumers Energy business owners to achieve this level of high performance by:

- Identifying the applicable new construction baseline and performance targets for multifamily building types in the Consumers Energy territory.
- Evaluating energy and cost savings for design strategies and processes.
- Recommending holistic energy efficiency measures that collectively meet the all-electric and ZNE-ready goal for a multifamily project.
- Providing actual examples of multifamily projects that are designed to or operating as all-electric buildings in cold-climate locations.
- Representing a range of all-electric appliances and technologies currently available in the residential and commercial marketplace.

Why Are All-Electric Apartments Popular?

All-electric homes are well known in America: most homes have used electric water heaters since 1950, have used electric space heating since 1970[2], and today electric stoves are now 61% of annual sales[3] and electric laundry dryers are 88% of annual sales.[4] Several benefits of all-electric homes are discussed below: they have less of an impact on the environment; are lower cost and faster to build for developers; and provide a healthier indoor environment to their occupants.

Less Impact on the Environment

An all-electric home produces less total pollution compared to a mixed-fuel home (even when they use electricity created by a cleaner natural gas power plant) (Figure 1). This is mostly due to heat pumps being highly efficient (300% efficient vs. 95% efficient gas heating), most grids using some portion of renewable energy, and the methane leakage that occurs at natural gas power plants.[5]

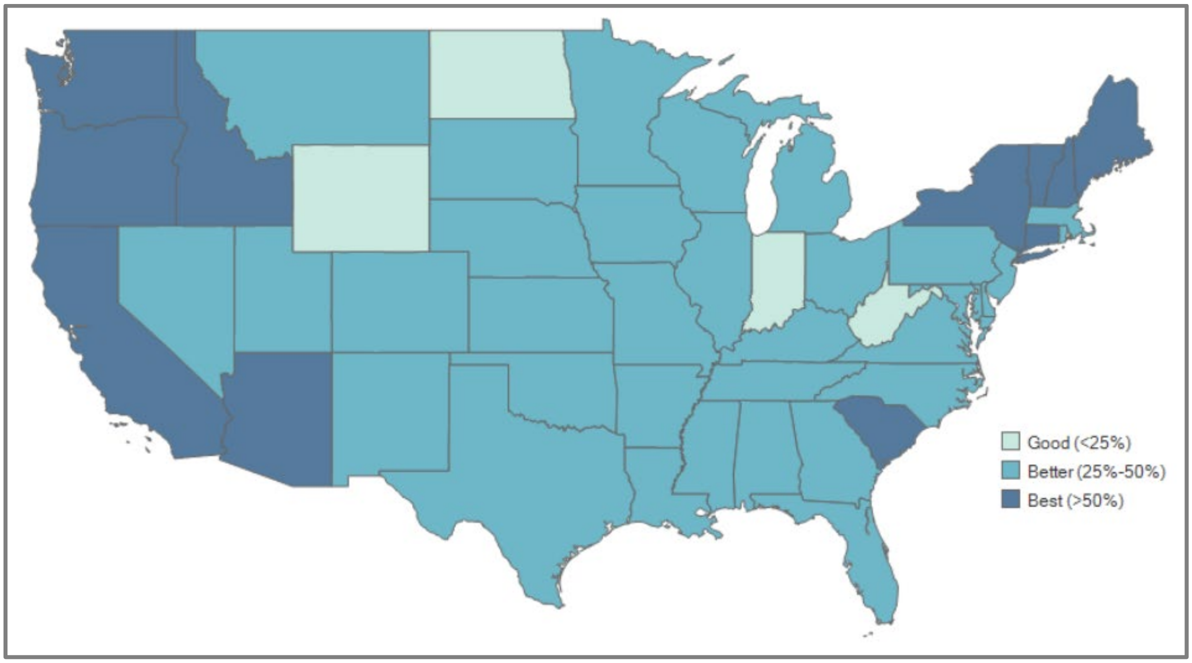


Figure 1: Electrifying space and water heating with heat pumps can reduce average household GHG emissions in all states.

All-electric homes will continue to produce less emissions as the grid gets cleaner. In their latest Clean Energy Plan, Consumers Energy demonstrated their leadership in clean energy by forecasting renewable energy capacity levels of 42% and 56% in 2030 and 2040 respectively (currently the state of Michigan requires 15% of the state's electricity to come from renewable sources).[6] This paves the way for all-electric homes to be completely powered by renewable energy generation in the future, an opportunity that mixed-fuel homes will never be afforded. The global community of cities, states and nations have identified building electrification as the fastest, least expensive, and most likely to succeed at reducing global emissions according to the Environmental Defense Fund. [7,8]

Lower Cost and Less Complex to Build

One in four homes is currently built all-electric.[9] This trend began in the 1950s, and now electricity is the fuel with the largest market share growth since 2010 in almost every county in the United States, including most of Michigan. Building all-electric continues to grow nation-wide as developers and contractors continue to seek lower construction costs and complete their projects faster and with simpler infrastructure.

"The cost of bringing natural gas to a building site is expensive. And you can generate electricity with solar electric panels to lower bills. **All-electric is what we call a no brainer**."

- ***Chris Dart, President of Danco Communities***, *the largest rural affordable housing developer in far Northern California*

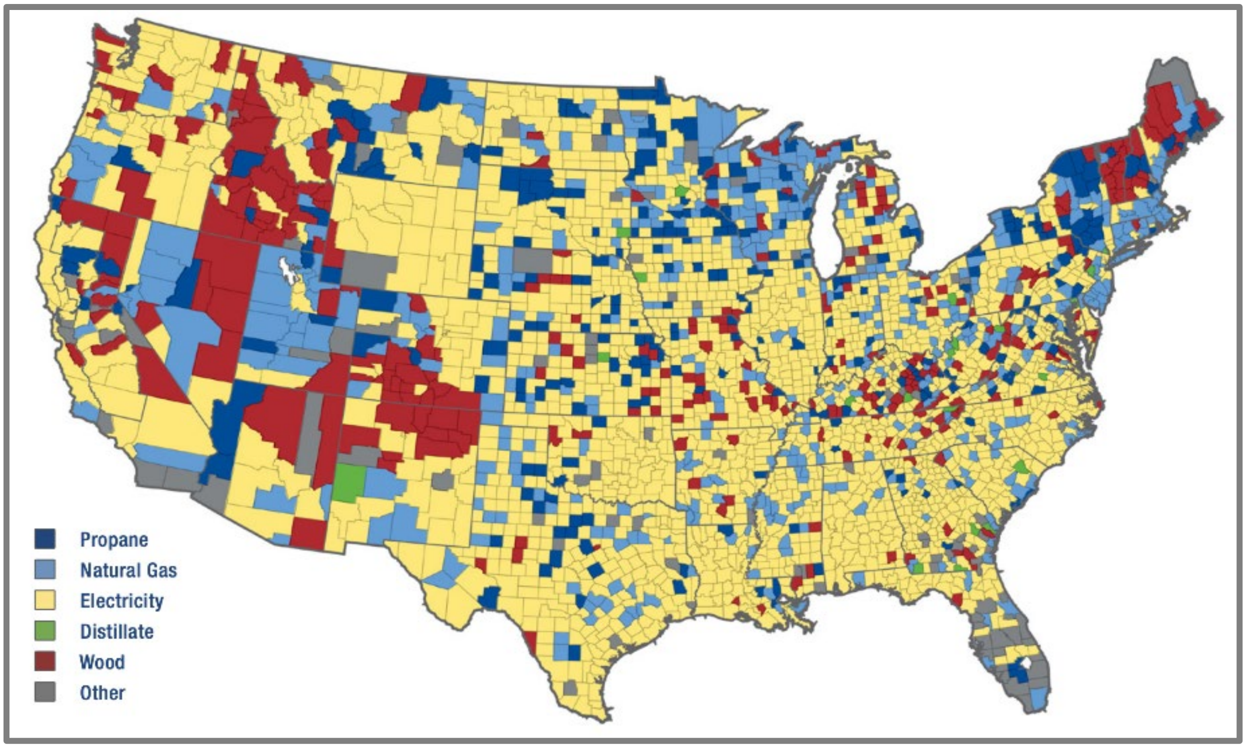


Figure 2: Michigan, like the rest of the U.S., has seen strong market share growth in Electric space heating (yellow), and declines in Natural Gas, Propane and Wood.[10]

The cost of installing natural gas infrastructure in Michigan to a multifamily development is paid in three pieces:

1. The natural gas service line from the street to the meter can be privately installed or by the trusted energy provider **(Consumers Energy charges $200)** but requires heavy machinery and a skilled crew spending 3-5 hours of work per building, plus the design, permitting and inspection time delays.
2. The natural gas plumbing within the building to natural gas appliances costs from **$200-$800 per natural gas appliance,**[11] and requires more time for the design, construction, and inspections.
3. Natural gas combustion venting creates design challenges in apartments because of the requirement for venting to be 10' distant from windows and doors if vented horizontally or requires ventilation chases to the roof. The material, labor, design, and inspection of even a dryer vent costs between **$80 and $1,000,**[12] and slows construction. Electric condensing and heat pump dryers require no vent at all.

Netting a Profit with Solar Power on Michigan Multifamily Developments

Installing solar panels on apartments was so financially successful in California that it became a requirement of the building energy code in 2020 to install a roughly 2kW solar array for every apartment in a 1-3 story development. Developers in Michigan can also adjust rents when upgrading in tenant-serving solar electric arrays that are up to 150kW,[13] enough to 100% solar offset roughly 50 apartments. In both affordable[14] and market rate multifamily housing, rents can be predictably adjusted to reflect the reduced bills from tenants' solar power. Increased rents result in an increased permanent loan that is greater than the cost of the solar array, thus netting a profit for the developer while still providing an equitable rent to occupants.

Improved Tenant Comfort

Ensuring tenant comfort spans from making sure the equipment we use is efficient and provides heating or cooling when and where we want it, but also extends to the appliances we use every day. In 2020, Consumer Reports ranked the top 8 stoves, and the best stoves were electric induction stoves, ranked #1-2, #4-5, and #8, with a smooth top electric resistance stove at #6. Cooking with electricity means one has access to the best stoves on the market — the fastest, easiest to clean and most controllable stoves made. Heating your home with a heat pump can be similarly luxurious — a furnace turns on-and-off intermittently, blowing very-hot heat with a fan which can be noisy and cause disturbance, while a heat pump fan is always on at a quieter speed and evenly heats your home, so you are always comfortable. In addition, HVAC solutions like ductless mini splits provide heating and cooling control by room, making sure each room is comfortable for all occupants.

Resilience of All-Electric Homes

[15].

All-electric homes can be built resiliently by insulating and air sealing to make sure temperatures stay stable during power restoration events, by having battery backup storage, and by reducing peak natural gas demand on the grid.

Well insulated homes are more resilient during power restoration efforts.

During extreme cold weather events, like a polar vortex, the electrical grid can become strained and our homes ever more important as a shelter from the elements. Homes that have passive design features such as a high-performance envelope that can optimize the heat gain when it comes to exterior weather conditions are much more resilient than the contrary (uninsulated and leaky homes) during power restoration. One study modeled various homes and tracked indoor air temperatures during a power restoration and cold snap, it found that for a typical 1950's home with no insulation temperatures dropped below 40° in only eight hours compared to a 2009 IECC code compliant building dropped below 40° after 45 hours.[16] The above and beyond the code minimum homes (a Net Zero Energy Ready home and a Passive House home) stayed above 40° for 61 and 152 hours.

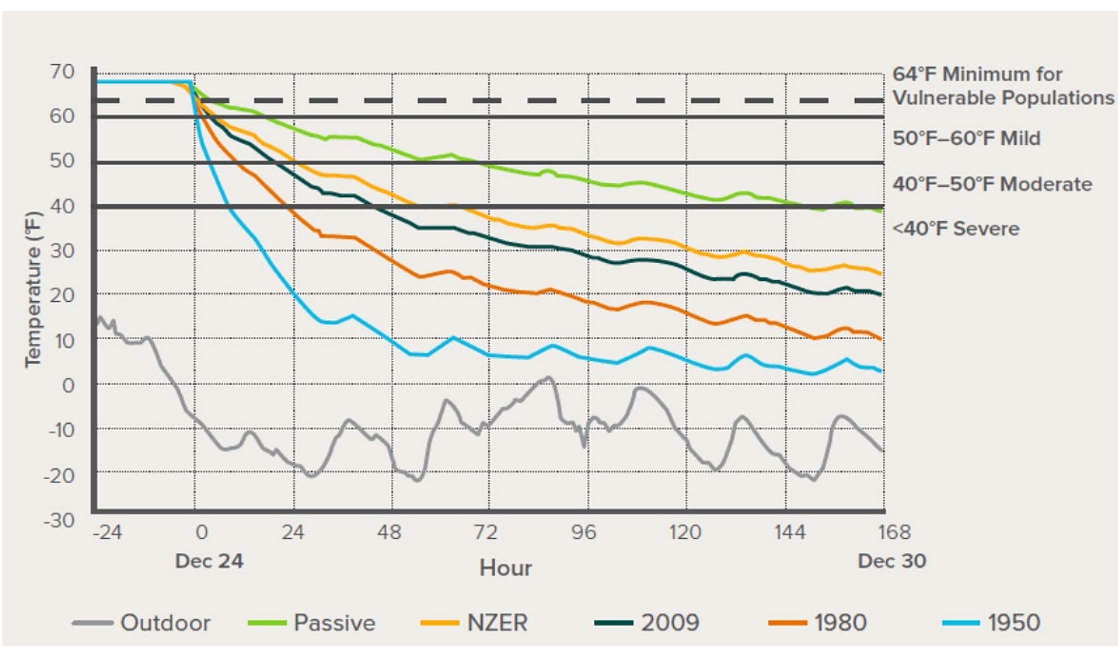


Figure 3: Modeled homes indoor air temperature - without power in an extreme cold climate event. [16]

Homes that are modestly insulated like the 2009 IECC code compliant home can protect their occupants for a few days, which covers the average power restoration in Michigan (97 minutes).[17] Resilience can be built into homes (by having more insulation and better windows) and can provide a buffer of a few days from chilling outdoor temperatures during power restoration and cold weather event.

Electric battery back-up can provide longer duration resilience during power restoration efforts

For longer restoration efforts, having an electric battery can power a home for multiple days. If homeowners are upgrading to an electric vehicle, their EV can also be used as a resilience feature by using it to power your home. Two companies are soon launching vehicle-to-home (V2H) charging in the United States (Wallbox and Ossiaco) but V2H charging has been common in other countries for years, providing people with essential back up power. For example, the Nissan Leaf has been able to power homes in Japan during restoration efforts, powering essential loads in the home for more than two days in one example.[18]

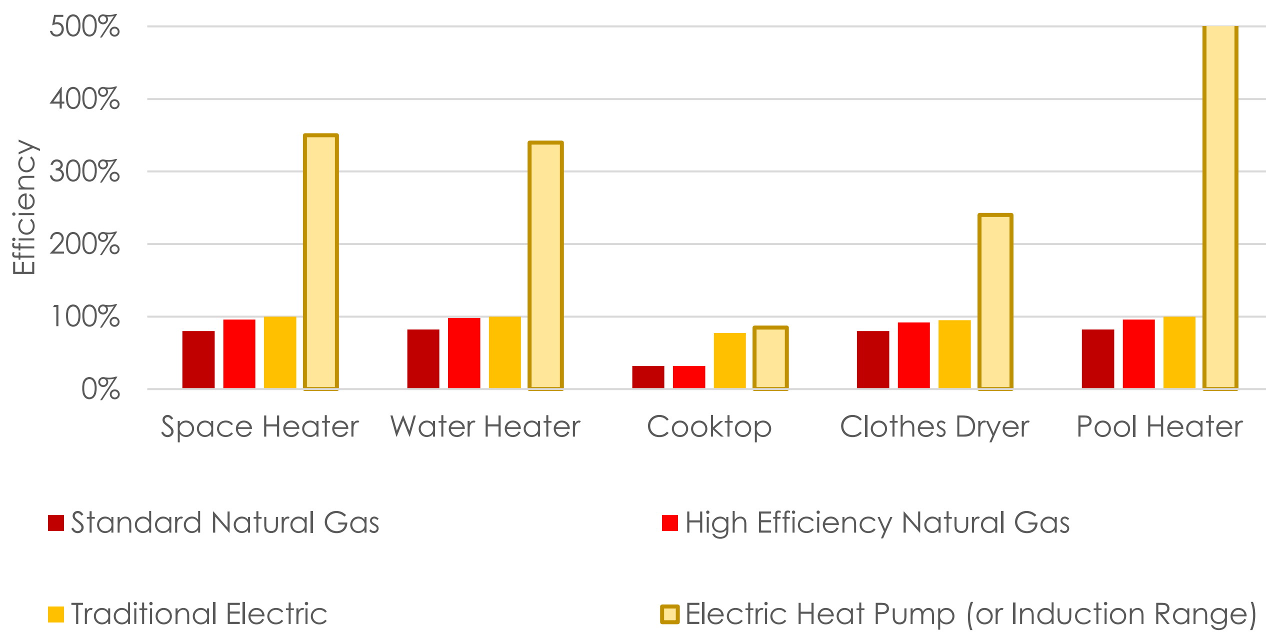
Modern natural gas appliances need electricity

Even if loads in a home are powered by natural gas, modern natural gas appliances are reliant on electric components. For example, new natural gas furnaces and water heaters have an electric igniter and cannot be lit manually like older systems with a pilot light. Additionally, furnaces need an electric fan to blow heat around a house. Although gas stove tops will work in restoration situations, electric fans to vent out the harmful combustion pollution will not operate, along with smoke and carbon monoxide detectors, so operating gas appliances can become unsafe.

All-electric homes can reduce winter peak natural gas demand

Both the electric and natural gas power networks are strained during extreme cold weather events. The following chart shows the comparison of efficiencies for equipment used in the home. By using energy more effectively such as in the heat pump case, all-electric homes can reduce the need for natural gas for home heating during peak demands in the winter.

Figure 4: Comparison of energy efficiency ratio for equipment types in the home.
(Source: DNV for San Mateo County Electrification Study)



Typical Multifamily Building Characteristics in Michigan

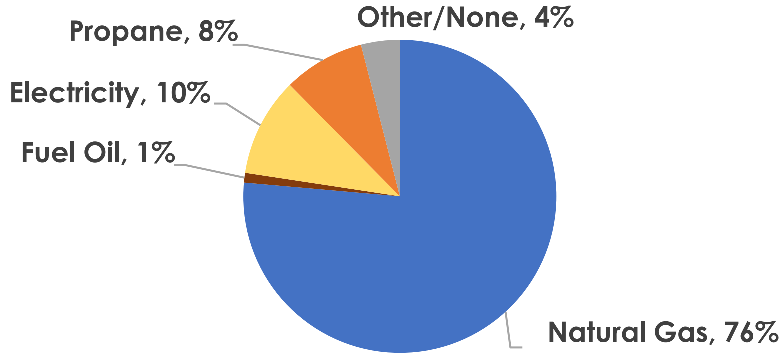


Figure 5: Fuel for space heating in Michigan residential homes in 2019. [19]

Multifamily buildings in Michigan range from large apartment complexes to smaller, town home style apartments, with a total of 13% of the building stock in 2017.[20] Of these multifamily buildings in Michigan, 2.5% are 2 units, 2.6% are 3 or 4 units, 4.2% are 5 to 9 units, 3.6% are 10 to 19 units, and 5% are 20 or more units.[20] In the Midwest in general, the age of the multifamily building stock varies — however, peak multifamily construction was in the 1970s, and buildings have become bigger since 2000 with more units and mid-size and smaller multifamily construction tapering off.[20] There has not been substantial energy efficiency measures in the multifamily building stock in the Midwest, most appliances are not ENERGY STAR® rated and there are not many programmable thermostats — however some buildings had lighting upgrades, have double or triple pane windows, and report adequate insulation levels.[20] For space heating in Michigan specifically: 76% of homes are heated by natural gas, 10% by electricity, 8% by propane, 1% by fuel oil, and 4% are other from other sources (Figure 5). Since most of the residential buildings in Michigan are heated by natural gas, and a majority of the multifamily building stock is older, there is an opportunity for the new stock of multifamily buildings being built all-electric today to bring energy savings and improved comfort to the residents of Michigan.

Overview of All-Electric HVAC Solutions

In the back of the guide is a comprehensive all-electric product guide; the tables below are summaries of all-electric solutions for multifamily application and their rated operating conditions. For each system, the heating capacities and the lowest ambient air temperature is provided. Some heat pumps do not have a low temperature cut off; however, their heating capacity will be reduced at lower temperatures. For the products that do cut off at lower temperatures, most have electric resistance back up that will work in any outdoor temperature. In a nutshell, heat pumps for space heating and domestic hot water are technically advanced to work in cold climates and are more efficient, comfortable, and cleaner than their natural gas equivalents.

Table 1: Overview and highlighted products for of HVAC, DHW, Cooking, and Laundry categories.

HVAC Heat Pumps	Ductless	Ducted
	 *VHP 2.0 by Ephoca (Both Ductless and Ducted)*	 *Pentacare v12 by Minotair*

Packaged Terminal Air Source Heat Pumps save ~30% in installation costs compared to mini-split systems of the same size by avoiding installation costs of refrigerant lines.	 *HPAC 2.0 by Innova*	
Mini-Split Air Source Heat Pumps can provide more heat than packaged systems with their greater surface area; the narrow profile fits on rooftop parapet walls and patios of apartment buildings.	 *Arctic NextGen by Haier*	
Full Size Split Air Source Heat Pumps provide more heat than mini splits but at slightly lower efficiencies due to pumping refrigerant in VRFs and blowing air through ductwork.	 *Variable Refrigerant Flow 38VMH by Carrier*	
Hydronic Heat Pumps for Radiant Floors and Ductwork need 70F-130F from a Ground Source Heat Pump (e.g. Water Furnace), while Radiators require high temps (150F-180F) provided by a specialty hydronic heat pump (like the Transom Hatch).	 *700A11 by Water Furnace*	 *Transom Hatch*
Domestic Hot Water	1 to 2 Apartments	Central to All Apartments
	 *Prestige by Rheem/Ruud*	 *020-050 line by Arctic*
Cooking Ranges	Radiant	Induction
	 *WFE320M0ES by Whirlpool*	 *FFIF3054TS by Frigidaire*
Laundry Dryers	Condensing Washer/Dryer	Heat Pump Dryer

	 *WM3998HBA By LG*	 *WHD560CHW by Whirlpool*

Table 2: Heating capacity and the lowest ambient air temperatures for various HVAC and DHW product types. The low temperature represents either a specific product or several products (refer to the full Product Guide at the end of this document for more information.

HVAC Systems	**Heating Capacity Range**	**Lowest Ambient Temperature**
Energy/Heat Recovery Ventilators with Heat Pumps	5000 - 11,000	No Low Temp
Packaged Terminal Air Source Heat Pumps	3,000 - 12,000	-14
Mini-Split Air Source Heat Pumps	7,000 - 60,000	-31
Split Ducted Heat Pumps	19,000 - 60,000	-10
Variable Refrigerant Flow Heat Pumps	72,000 - 400,000	-13
Hydronic Heat Pumps	5,000 - 380,000	-30
Domestic Hot Water Systems	**Heating Capacity Range**	**Lowest Ambient Temperature**
Individual Tank Heat Pump Water Heaters	4,000 - 15,000	-30
Large Central Heat Pump Water Heaters	15,000 - 600,000	-15

New Construction Multifamily Building Characteristics

In 2017, Michigan adopted the 2015 International Energy Conservation Code (IECC) and ASHRAE 90.1 2013 as its governing state-wide building energy codes. For this design guideline, we assumed that any recommended new building systems or components will at a minimum meet ASHRAE 2013 prescriptive requirements. For cases where the building component or system is recommended to exceed ASHRAE 90.1 2013 level performance, the increase in percentage or factor is noted.

Modeling Analysis

To support the technical design solutions recommended in this all-electric design guide, an energy model representing a low-rise multifamily prototype building was developed. The 'Baseline' energy model was created as a representation of a new construction multifamily building that complies with the IECC 2015 minimum efficiency requirements. The 'Proposed' case represents the same building with a package of energy conservation measures (ECM) implemented to exceed the code minimum requirements.

Methodology

A 'right steps', 'right order' approach was used in the energy savings and lifecycle cost analysis to accurately assess true savings of each recommended ECM:

a) Passive strategies
b) Improved Envelope

c) High Performance Systems
d) Renewables

Each of the ECMs (details of each provided below) were incrementally added to the Baseline model with the final Proposed case representing a complete package of high-performance design measures. Two pathways were modeled for the cooling, heating, and hot water system ECMs: 'high efficiency' and 'premium'. The purpose in analysing both high efficiency and premium tiers was to provide a comparison of energy and cost saving options available on the market for building owners.

Energy Modeling Simulation Engine

Rem/Rate 16.0.4 was used as the modeling software to conduct the energy calculations for this design guide. The Rem/Rate software suite was chosen as it allows for full consideration of dynamic thermal performance of a multi-story residential building and offers a wide variety of analyses, including but not limited to the following:

- U.S. EPA ENERGY STAR® Certified Homes v3.x and Multifamily New Construction v1.x Home Analysis
- DOE Zero Energy Ready Home Certification
- Energy code compliance (IECC 1998 - 2018)
- Heating and cooling equipment sizing

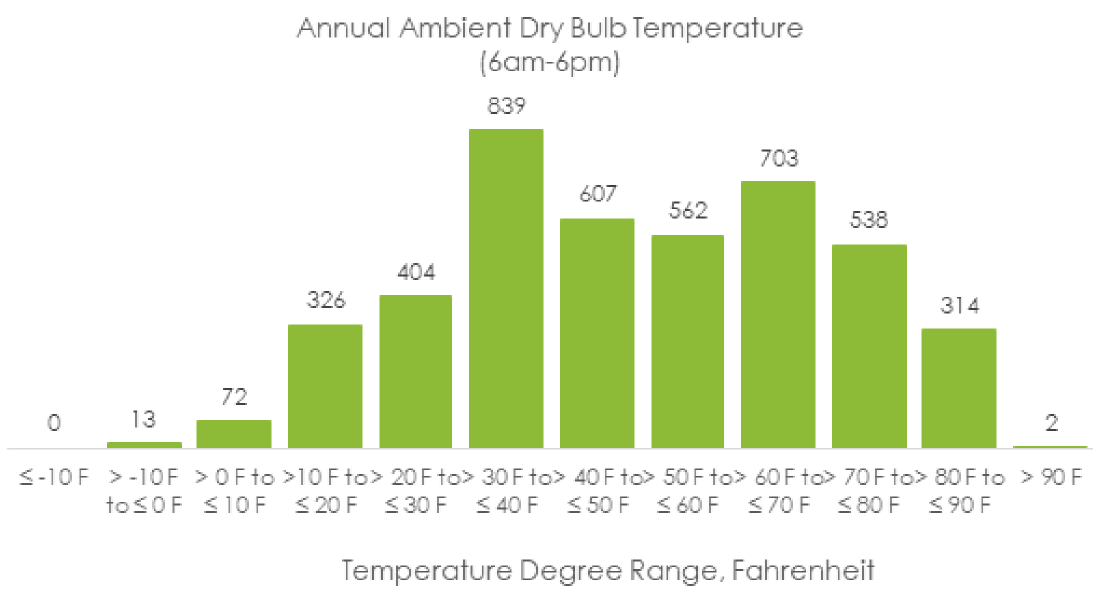
The specific outputs used for the energy and cost analysis will be discussed in detail in the results section of this guide.

Weather

The Grand Rapids weather station was selected as a representative climate zone for Consumers Energy territory. The weather data contains records on solar radiation, temperature, humidity, sunshine duration and wind speed and direction. The energy model uses the normalized weather data for its annual simulation that informs climate-specific energy efficiency recommendations.

The ambient temperature conditions experienced in Grand Rapids, Michigan over the course of one year are illustrated in the chart below:

Figure 6: Annual Ambient Dry Bulb Temperature for Grand Rapids



Baseline Conditions

Table 3: New Construction, Baseline Low-rise Multifamily Building Assumptions

BUILDING ENVELOPE	• Roof: Above deck insulation, with Attic, vented. R38 batt Insulation and R-13 continuous insulation • Exterior walls: wood frame 2x4 fiberglass with minimum of R13 batt insulation and R-7.5 continuous insulation • Infiltration: 0.2 Air Changes/Hour (ACH) • Glazing: Double pane, U value = 0.55 Btu/h ·ft² ·F, SHGC = 0.32
LIGHTING & CONTROLS	• A minimum of 75 % of the lamps in permanently installed lighting fixtures are high-efficacy lamps or 75% of permanently installed lighting fixtures contain only high efficacy lamps • Occupancy controls or time-switch controls in common areas • Daylighting controls: daylight responsive controls in daylight zones • Exterior lighting: 600W individual lighting allowance
HVAC	• Air distribution system: Multi-zone air-handling units • Heating/Cooling system: Packaged Terminal Heat Pump per dwelling unit. Min. efficiency required by IECC 2015/ASHRAE 2013 • Domestic hot water: in unit electric resistance storage water heaters. Min. efficiency required by IECC 2015/ASHRAE 2013

Energy Conservation Measures

To align with the Consumers Energy Zero Net Energy Companion Program energy targets, the energy performance of the Proposed building design is targeting the following criteria:

- Annual energy use intensity (EUI) of 25 kBtu/ft² and at least a 40% annual energy savings reduction
- The proposed project must use 100% electricity (i.e., no natural gas, propane or district heating used onsite)
- New construction multifamily building type

The ECMs identified are specific to the Consumers Energy territory and incorporate strategies that reduce the building's energy use. There were two paths investigated for HVAC/DHW system efficiency measures. The first is a high efficiency HVAC system and a high efficiency water heater solution (ECM 6a & ECM7a) which will be considered as the 'Better' proposed case in this design guide. The second, a premium efficiency HVAC and premium efficiency heat pump water heater solution (ECM 6b & 7b) which will be referred to as the 'Best' recommended design case. The purpose in analyzing both pathways was to ensure maximizing efficiency of the equipment's impact is accounted for both in terms of customer payback period as well as the projected annual energy savings.

Figure 7: Recommended Energy Conservation Measures

ECM 1 – IMPROVED THERMAL INSULATION		Increase wall insulation: Rock wool insulation for cavity rated at R3.5-4/1", 2" of Exterior rigid insulation (total assembly R value of 21) Increase roof insulation: R-38 batt attic insulation
ECM 2 – HIGH PERFORMANCE GLAZING		High performance glazing with total assembly U-factor of 0.2 $Btu/h \cdot ft^2 \cdot F$ (COG U - 0.16 $Btu/h \cdot ft^2 \cdot F$) and SHGC of 0.23
ECM 3 -HIGH EFFICIENCY APPLIANCES		Replaced Baseline appliances with ENERGY STAR rated: Washer – ENERGY STAR 2018 rated Dryer – heat pump technology, ventless Oven – Induction range
ECM 4 – LED LIGHTING & SMART PLUG LOAD		100% LED fixtures and smart plugs to manage receptacle load
ECM 5 – HEAT RECOVERY VENTILATION		Mechanical ventilation with heat recovery (sensible heat effectiveness: 0.74)

'BETTER' DESIGN CASE	
ECM 6a High-efficiency hot water	High efficiency electric heat pump water heater with UEF of 3.45
ECM 7a High-efficiency mini-split system	Mini Split with SEER 24.5 & HSPF of 12.8 (efficiency equivalence to Mitsubishi model)

'BEST' DESIGN CASE	
ECM 6b Premium-efficiency hot water	Premium efficiency electric heat pump water heater with UEF of 4.0
ECM 7b Premium-efficiency mini-split system	Mini Split with SEER of 29.4 & HSPF of 14 (efficiency equivalence to Fujitsu model)

Each of these improvements, referred to as energy conservation measures (ECMs), have been modeled as cumulative iterations to the Baseline model.

Additional Considerations

Through an integrated, whole building design process the building owner and design team should consider all available passive and active strategies to achieve the optimal energy performance for their project. The following measures and recommendations are listed as additional options to further reducing building's energy use. Although they were not considered part of the detailed energy analysis for this design guideline, strategies to improving the thermal performance of these components have been provided below.

Insulating the Foundation

Thermal heat transfer through the foundation can be controlled by providing insulation between the interior and exterior environment. However, in some existing buildings insulation below the foundation may not exist. Insulating existing foundations can be an expensive and time-consuming process that involves locating existing utilities, excavating around the foundation perimeter, adding perimeter drainage, installing waterproofing membranes, installing rigid insulation along the perimeter walls and footings.

For this reason, this guideline does not recommend insulating existing foundations as an energy efficiency measure to target zero net energy. Instead, the recommendation is to evaluate improving the thermal resistance of the walls and roof of the existing building.

Shading

The use of shading devices can significantly reduce the amount of solar heat gain through openings in the building envelope. By intercepting sunlight before it reaches the walls and windows, shading devices can reduce the amount of cooling required by mechanical systems and improve the light quality of the indoor environment. Carefully designed sun control devices can allow solar radiation during the winter season when sunlight is desired to passively heat a building. Exterior shading is also used to control glare in interior spaces which can result in increased visual comfort and productivity. Additionally, shading devices can be used as design features to increase the visual appeal of building facades and provide additional mounting locations for solar photovoltaic panels.

Although not considered a specific ECM for this study, exterior and interior shading design is recommended as an effective strategy to improve the thermal performance of the building's envelope and therefore reducing a building's energy use overall. Additionally, it can improve the visual comfort for the occupants by blocking direct light and reducing glare conditions on work surfaces. It is recommended that design teams perform a solar shading analysis using daylight (or equivalent façade) modeling software so that the sun's position at various times of the day for each orientation can be assessed and the optimal solution for shading each façade is achieved.

Summary of Analysis

The results of this analysis conducted for this design guide can be summarized by looking at three components: energy and cost, greenhouse gas emissions and on-site solar generation. All three demonstrate that the Proposed 'Best' solution as being the most favorable pathway to achieving an all-electric, low-energy consuming, building design. It is important to note that the analysis followed to assess the energy and greenhouse gas footprint of the proposed solution should be considered as part of the decision-making process for the building owner and project teams. A successful multifamily building does not only have a lower carbon and energy footprint but over its longevity provides a livable, working space that positivity contributes to the health and comfort of the occupants and the surrounding environment.

Energy & Cost

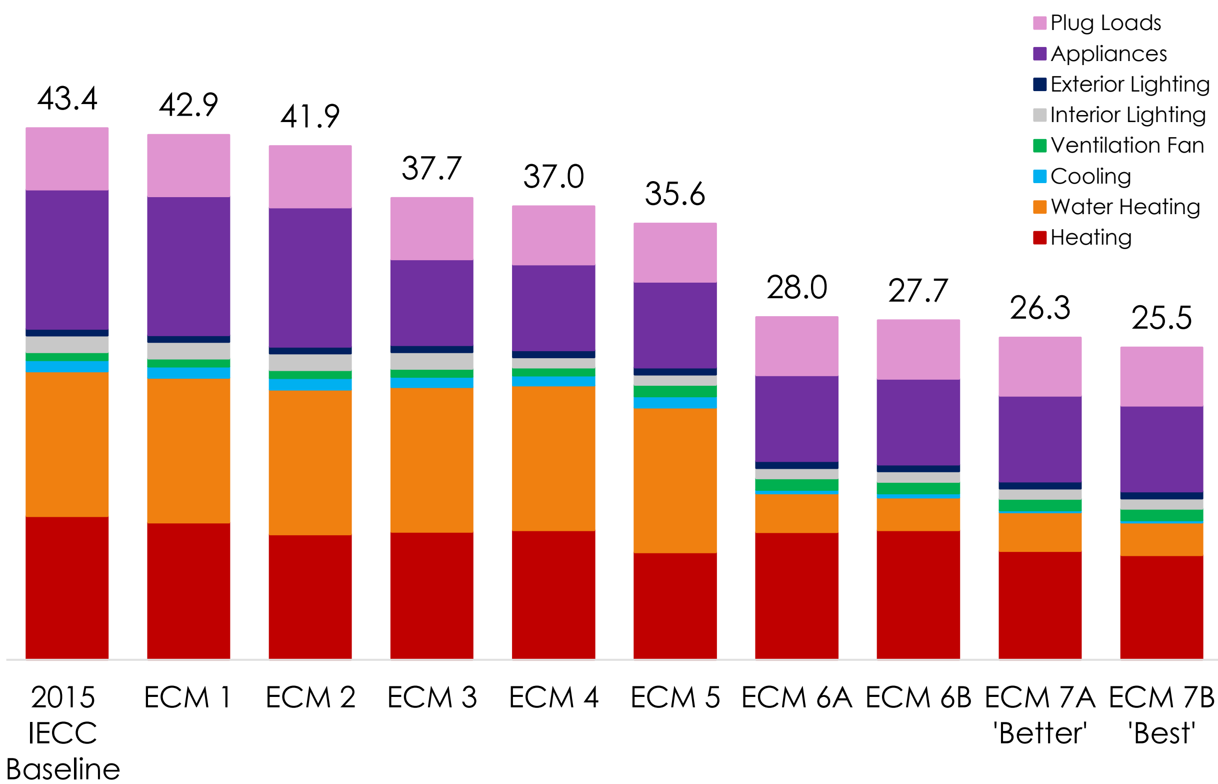
The following section lists the predicted annual energy use intensity (kBtu/ft^2) and energy savings for the multifamily building through cumulative implementation of the recommended energy conservation measures. The results demonstrate that if the Better design pathway is followed, the projected annual energy use intensity is 27.7 kBtu/ft^2 which results in total annual energy savings of 36.2% when compared to the baseline building energy use. If the Best design solution is chosen, then the resulting annual energy use intensity is approximately 25.5 kBtu/ft^2, which equals an energy reduction of 41.3% when compared to the baseline building energy use.

The table and chart below illustrate the annual energy use intensity and cumulative reduction because of implementing the recommended ECMs.

Table 4: Annual Energy Use Intensities and Cumulative Energy Savings for Baseline and ECM Iterations

	Energy Use Intensity (kBtu/ft^2)	Annual Cumulative Energy Savings (%)
BASELINE - Low-Rise Multifamily Building	**43.4**	**-**
ECM 1 – ROOF INSULATION and EXTERIOR WALL INSULATION	**42.9**	**1.2%**
ECM 2 – HIGH PERFORMANCE GLAZING	**41.9**	**3.4%**
ECM 3 – HIGH EFFICIENCY APPLIANCES	**37.7**	**13.2%**
ECM 4 – LED INT. LIGHTING	**37.0**	**14.7%**
ECM 5 – HEAT RECOVERY VENTILATION	**35.6**	**18.0%**
ECM 6A – HIGH EFFICIENCY WATER HEATING	**28.0**	**35.6%**
ECM 7A – HIGH EFFICIENCY MINI SPLIT (BETTER DESIGN CASE)	**27.7**	**36.2%**
ECM 6B – PREMIUM EFFICIENCY WATER HEATING	**26.3**	**39.4%**
ECM 7B – PREMIUM EFFICIENCY MINI SPLIT (BEST DESIGN CASE)	**25.5**	**41.3%**

Figure 8: Energy Use Intensity by Energy Conservation Measure and End-Use



For the financial analysis, the isolated and cumulative payback for each measure was calculated. The length of payback is compared against the measure's expected life as a performance assurance test for each of the recommended ECMs. For example, if an ECM's calculated payback is greater than the measure's expected life then there is very low probability that a building owner would agree to it unless there are other non-energy benefits associated. Each building owner would have their own definition of a reasonable payback for their project, and therefore, the results presented in the table below are intended to be a guide only. It is recommended that each project conduct their own cost-benefit analysis that is specific to their project, location and sustainability goals.

Table 5: Isolated and Cumulative Simple Payback by Energy Conservation Measure

	Expected Measure Life (years)[1]	Isolated Simple Payback (years)	Cumulative Simple Payback (years)
ECM 1 – IMPROVED THERMAL INSULATION	40 (building life)	32	32
ECM 2 – HIGH PERFORMANCE GLAZING	40 (building life)	20	26
ECM 3 – HIGH EFFICIENCY APPLIANCES	11	5	11
ECM 4 – LED LIGHTING & SMART PLUG LOAD	15	2	10
ECM 5 – HEAT RECOVERY VENTILATION	15	3	9
ECM 6A – HIGH EFFICIENCY HOT WATER	10	6	8
ECM 6B – PREMIUM EFFICIENCY HOT WATER	10	6	7
ECM 7A – HIGH EFFICENCY MINI SPLIT SYSTEM (BETTER DESIGN CASE)	15	9	8
ECM 7B – PREMIUM EFFICIENCY MINI SPLIT SYSTEM (BEST DESIGN CASE)	15	8	8

The table lists the envelope upgrades (ECM 1 & 2) with a significantly higher isolated and cumulative payback when compared to the other ECMs. Improving the thermal performance of a building's envelope can be costly and not always provide an adequate amount of energy savings to give a reasonable payback for the owner. Primarily this is because building energy efficiency codes are already requiring a tight envelope with continuous insulation rated at a high thermal resistance (R-rating) in all roof, wall and floor constructions. For example, in this analysis of a multifamily building located in Climate Zone 5A, the IECC 2015 requires a minimum of R-38 batt insulation in the roof and R-19 for external walls with a minimum R-7 to be continuous. Therefore, adding supplemental insulation above what is already required by code results in minimal energy savings (only 1.2% annually) as the thermal performance of the envelope levels out. Consequently, generating a much higher payback for the measure.

Similarly, the results for ECM 2, the high-performance glazing measure, are another example of unfavorable payback when considering annual energy savings against first costs. Glazing is one of the most expensive components to a building's construction and the addition of a third pane, as recommended in this measure, means that the glass is filled with krypton gas which is much more expensive than argon (typical for double pane glazing). The weight of the windows increases significantly too when adding a third pane to the assembly which effects the installation costs on site.

Further, when selecting a suitable glazing product in a cold climate such as Michigan, it is important to consider both the thermal conductance (U-value) and solar heat gain coefficient (SHGC) of the glass and total assembly. For example, choosing a glazing product that has low SHGC such as triple pane windows may not always be the best solution in cold climates during winter as it means that very minimal solar energy is coming through the envelope when heating is needed the most. As a result, the energy savings that are generated in summer are offset by the increase in heating energy required during winter.

Both the high first costs and small energy savings for ECM 2 results in a higher payback compared to the other measures.

It is well documented that optimizing a building envelope's thermal performance based on the climate will generate additional benefits for the building owner beyond just annual energy savings.[21] A

[1] Expected measure life for each measure was taken from Consumers Energy 2021 Measure Database.

continuously insulated and airtight building skin will result in lower operational and improvement costs over the course of the building's life and provide ongoing non-energy benefits such as thermal and visual comfort for the occupants, improved indoor air quality and overall building resiliency.

For multifamily buildings especially, the occupants (tenants) appreciate the value of living in a building that improves their overall health, comfort, and well-being in conjunction with lower monthly costs. Moreover, a tenant is more likely to live longer in a sustainable building which provides higher rent retention for the developer.[22]

Peter Skornia, President of Bazzani Building Company, a prominent multifamily developer in Michigan has spoken about their decision process when it came to envelope design criteria on the Bradford Station project:

"Balancing first and operational cost, tenant features and affordability are key to any successful development. Providing a good thermal envelope, lots of natural light and energy efficient building systems means tenants have a safe, comfortable place to live and work, supporting high tenant retention and improved profits."

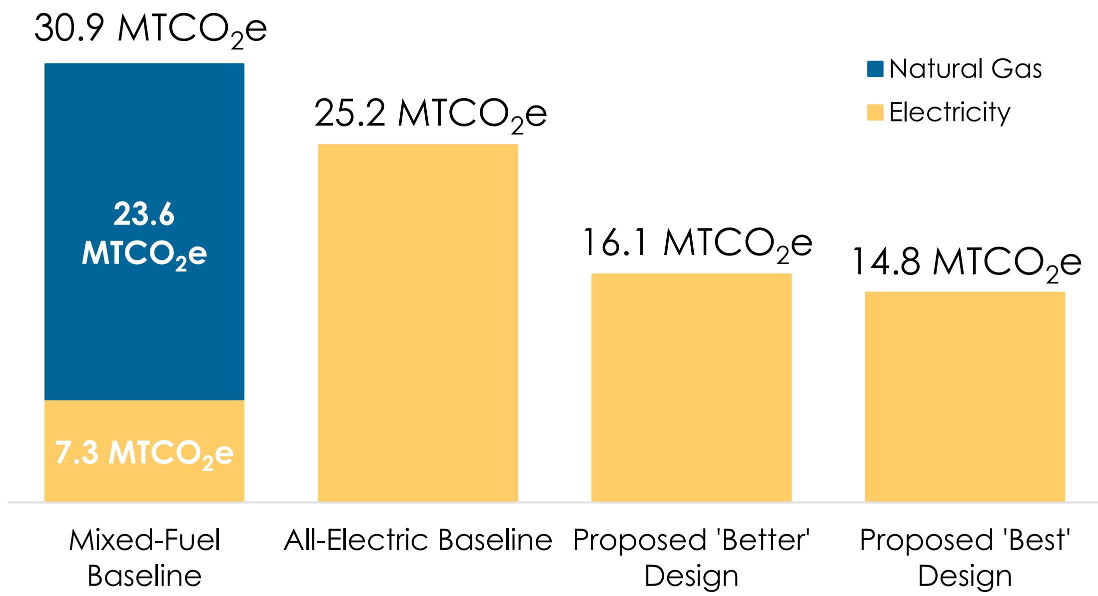
Both the 'Better' and 'Best' cases are holistic solutions for building owners that are seeking to decarbonize their building's energy footprint, obtain significant annual energy savings for a reasonable payback. Adoption of the 'Better' design solution will generate a cumulative payback of 8 years and, implementing the recommended 'Best' design solution will also result in a similar cumulative payback. This demonstrates that the delta in annual energy savings and capital costs between the two design solutions is relatively consistent.

Greenhouse Gas Emissions

The GHG emissions for the Baseline and the two proposed design cases were calculated and evaluated against an equivalent IECC 2015 Baseline mixed-fuel multifamily building.

The following chart shows the comparison between the four buildings in terms of the greenhouse gas emissions consumed on an annual basis. It demonstrates that the "Proposed 'Best' Design" case emits 14.8 $MTCO_2e$ of greenhouse gases annually, a 52.1% reduction when compared to the mixed-fuel baseline and 41% reduction when compared to the all-electric Baseline.

Figure 9: Total Building Emissions



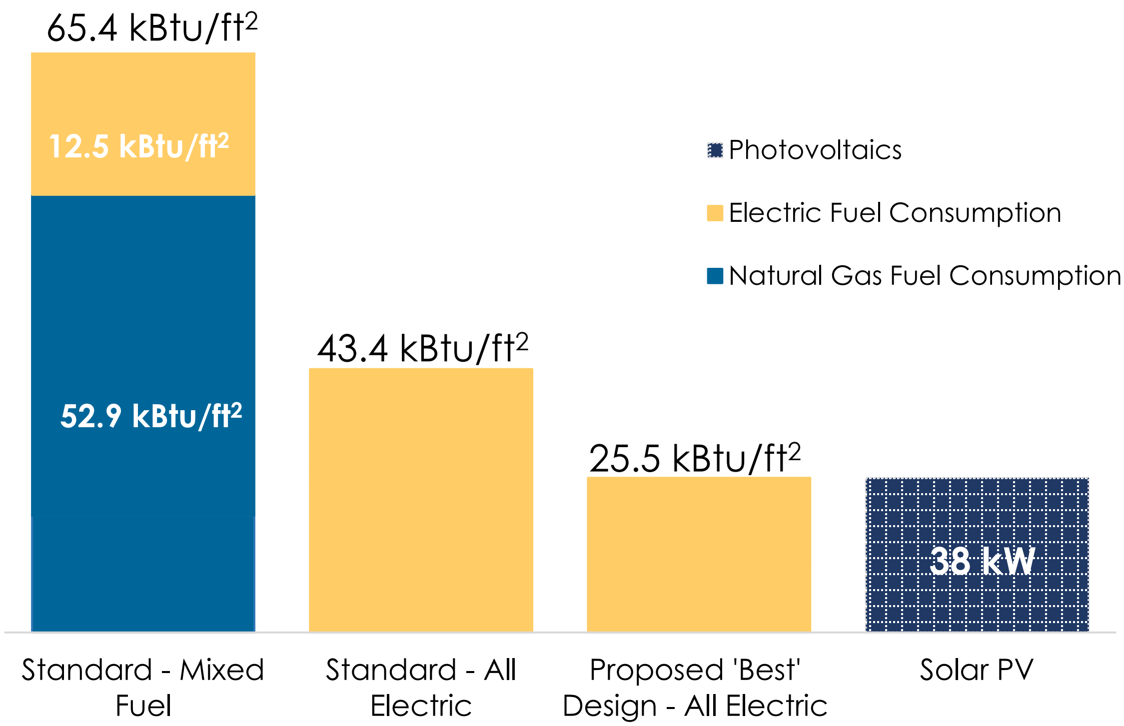
On-Site Solar Generation

Although the ZNE program is unable to provide business owners with renewable incentives due to the program's regulatory structure, the generation of electricity on site is a key component to any zero net energy project. On-site solar generation (through photovoltaic arrays installed on the roof) was calculated to offset the 'Best' design's annual energy use and achieve zero net energy for the building. A 38kW[2] solar array was calculated to generate enough electricity to offset 100% of the Best design's projected annual energy use (25.5 kBtu/ft^2).

The addition of a solar array also has a great impact on shortening the payback period of the cumulative measure cost for the 'Best' design. It is calculated that with the renewable energy generation on site, the cumulative payback period for the project is reduced to 6 years.

[2] Assumptions for the solar array generation are based on 35.3° tilt, south facing array with 12% system losses in Grand Rapids, Michigan. NREL's PV Watts Calculator was used for the calculations.

Figure 10: Zero Net Energy Analysis for Low-Rise Multifamily Building



Conclusion

This design guideline provides a detailed roadmap for a building owner and design team to achieve zero net energy ready on a low-rise multifamily building project in Michigan. As proven through the modeling analysis in this design guide, when the recommended energy conservation measures are implemented, the resulting design solutions (Better and Best) will significantly reduce the energy footprint of the building.

All recommendations listed in this design guideline encourage a healthy and relatively comfortable place for multifamily occupants. On top of the considerable energy savings, the ZNE ready all-electric approach brings benefits such as thermal comfort, increased building resiliency, dependable space conditioning, water heating and lower greenhouse gas emissions. The incorporation of the recommended design elements and systems into the project's design and construction will help in assuring that the building will not only be enjoyed by the residents but a more resilient building design to be enjoyed in comfort by future occupants. The 'All-Electric Product Guide' included in the next section provides a catalog of available, all-electric products that can be used in multifamily projects.

Case Studies

The case studies below provide examples of all-electric homes in the Midwest and north east regions of the United States, showing that all-electric buildings are efficient, comfortable, and affordable, even in the coldest climates. Solara, Bank Flats, and the R-951 Residence were all built to meet the Passive House standard – they take insulation and air tightness to the next level which can reduce the size of the mechanical equipment and hold indoor temperatures for longer when the power goes out. These case studies show that meeting the most stringent envelope building certifications can be cost effective for developers. However, the case studies shown located in Michigan prove that buildings do not need extremely high levels of insulation and building tightness to be cost effective for developers, efficient in operation to keep bills low, and comfortable for their residents.

Downtown Ludington Apartments, Ludington, Michigan and Capital Park Apartments, Detroit, Michigan

Both the Ludington and Capital Park Apartments by Concept Design Studios are all-electric multifamily projects located in Michigan. They are shown together because their building specifications are similar – above code insulation (R26 walls, R47 attics), with code minimum efficiency heat pumps for heating and cooling, electric resistance water heaters, 100% LED lighting and exhaust only ventilation. Even without a solar array, the energy bills are still an affordable $60-70 per month (Estimate for Ludington is show in below).

Downtown Ludington, Michigan offers 30 affordable apartments for small families and senior citizens, with commercial spaces for rent on the ground floor. The complex's location reduces vehicle miles traveled and is rich with walking distance amenities, only 7 blocks east of Lake Michigan and centrally located around restaurants, cafes, and shops. Similarly, Capital Park has a comparable number of units and is located near the facilities of downtown Detroit.

Figure 11: The Downtown Ludington Apartments in Michigan (top). The exterior view of Capital Park Apartments in Detroit and heat pumps on the roof (bottom two)

Table 6: Summary of the building specifications of the Downtown Ludington Apartments

	1 Bedroom	2 Bedroom
Conditioned Area	712 sq. ft.	973sq. ft.
Window Specs	U-value: 0.29, SHGC: 0.21	U-value: 0.29, SHGC: 0.21
Wall and Attic Insulation	R-26/R-47	R-26/R-47
Air-Source Heat Pump	Heating: 8.2 HSPF, AC: 14 SEER	Heating: 8.2 HSPF, AC: 14 SEER
Resistance Water Heater	0.93 EF, 40 gallons	0.93 EF, 40 gallons
Ventilation System	Exhaust Only, 41 cfm, 3.2watts	Exhaust Only 62 cfm, 4.6 watts
Lighting	100% LED lighting	100% LED lighting
Estimated Energy Costs	$59/month; $705/year	$73/month; $877/year

The lessons learned on these projects was that it was lower cost to install a right-sized heat pump than an incorrectly sized gas furnace. Even the smallest gas furnace produces too much heat for code minimum modern apartments, unless one wants to buy an expensive modulating furnace. When a heating system is designed correctly, careful attention is paid to the heating requirement of the home (which depends on the building characteristics like insulation levels, location of the building, etc.). For an apartment with above code insulation, many furnaces are oversized, meaning they will provide too much heat to the space which may cause the furnace to turn on and off more than necessary and will be uncomfortable to its users. Heat pumps provide continuous heat at just the right temperature instead of blasting high heat on-and-off intermittently like furnaces. The better choice for cost and comfort is a heat pump that already has modulating capabilities (it can increase or decrease its amount of heating depending on outside temperatures). Additionally, heat pumps have heating and cooling built into them, so you get the benefit of two machines in one. In summary, all-electric construction with typical yet efficient building practices is achievable with low monthly energy bills for residents.

Port Crescent Apartments, Port Crescent, Michigan *(Retrofit)*

Figure 12: The Port Crescent Apartments

In 2018/19 this apartment complex was substantially renovated in accordance with the Home Innovation, National Green Build Standards. The major changes that were done to improve energy, material, and resource use included: replace unit entry doors and hardware with steel fiberwood door with an R Value of 1.8, install new unit carpet in 18 units, replace heating systems in all units, install new water heaters in all units, install new light fixtures in all units and the community building, blow in additional attic insulation, new sinks and faucets in all units, install new shower heads, spouts, and toilets in all units, and replace bathroom vent fans in all units. Various audits were performed on different unit types before and after renovations were made.
7 shows the energy use and cost for a one-bedroom unit before and after the renovations.

Table 7: Energy use and cost before and after the Port Crescent retrofit.

Annual Costs ($/yr.)	Before Renovation	After Renovation	Savings	Percent Savings
Total Methane Cost	132	0	132	100%
Total Electricity Cost	600	537	63	11%
Space Heating	148	188	-40	-27%
Space Cooling	0	13	-13	---
Water Heating	164	139	25	15%
Lights & Appliances	419	197	222	53%
Service Charge	120	60	60	50%
Total ($/yr.)	**1583**	**1134**	**449**	**28%**
Annual End-Use Energy Use (kWh)	**Before Renovation**	**After Renovation**	**Savings**	**Percent Savings**
Heating	206	2351	-2145	-1041%
Cooling	0	166	-166	---
Water Heating	2052	1733	319	16%
Lights & Appliances	5243	2464	2779	53%
Total (kWh)	**7501**	**6714**	**787**	**10%**

The lessons learned on this project was that going all-electric reduced the total energy bill of a one-bedroom apartment by 28% ($450 dollars per year) and reduced the amount of energy used by 10%, even after adding cooling. The changes that reduced the energy bill the most were the lighting and appliance updates and the change in service charge cost.

Bradford Station, Grand Rapids, Michigan

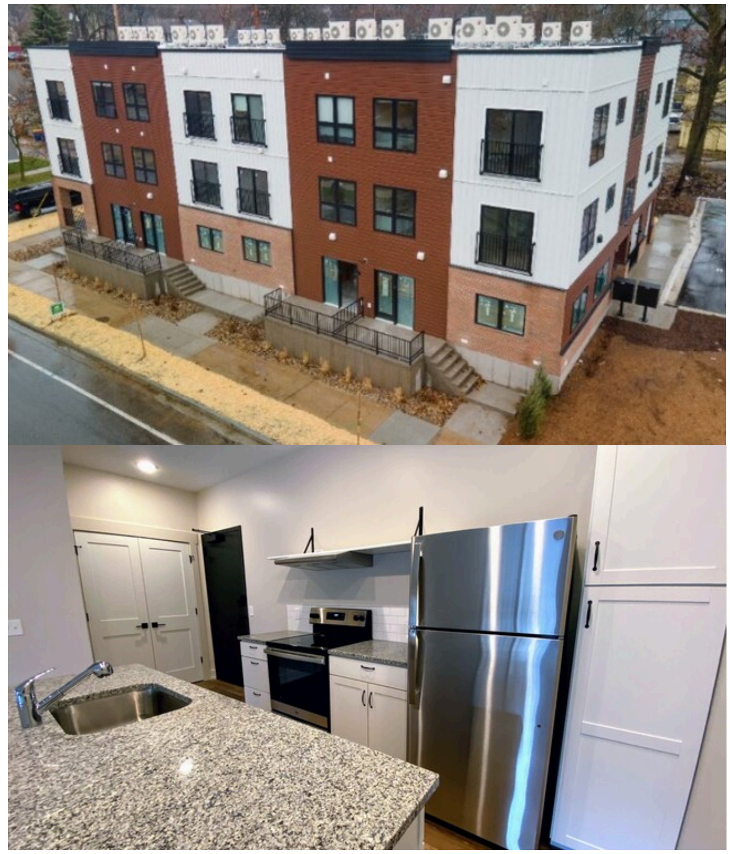


Figure 13: Bradford Station rendering and post construction in Grand Rapids, Michigan

Michigan is ranked as one of the top ten coldest states in the United States. In January, the coldest month, temperatures frequently drop down below 0°F and can even go as low as -20°F. It can be hard to imagine how buildings and homes can be built to zero carbon specifications with a high heating load. However, Bazzani Building Company is proving that to be more than possible. One of their latest projects, the Bradford Station is a prime example of their goal to do what is best for the environment and residents. Bradford Station, opened in Fall 2020, is a 16,500 square foot all-electric building offering 23 studios and one-bedroom apartments, and a ground floor retail space. It is on track to be LEED certified and Zero Carbon. Each apartment has a self-contained HVAC system, meaning there is no mixing of air or bacteria between apartments. To achieve this high standard of ventilation, there is an energy recovery ventilator in each apartment which also provides the required ventilation per code. Each apartment has a dedicated mini-split heat pump that will provide adequate heating and cooling to meet the occupant's thermal comfort needs. This was Bazzani's first all-electric apartment complex, and they want to do all-electric again, although next time with heat pump water heaters instead of electric resistance water heaters to have additional energy savings.

Key design and construction partners for the HVAC and electrical systems in the project:
Mechanical Contractor - Hendricks Heating and Air Conditioning
Electrical Contractor - Hardy Electric
MEP Consultant - MJW Design

HVAC	Mini-split heat pump system Heating Efficiency: 12 HSPF ERV providing ventilation in each unit
DHW	Electric Resistance Water Heater
Cooking	Flat top electric stove/oven combo
Envelope	Exterior Walls: Wood frame with R21 batt insulation and additional 2" of continuous insulation Roof: Flat built-up roof with R38 batt insulation and low solar reflectance index rating on the exterior

Solara Luxury Apartments, Rotterdam, New York

Solara Luxury Apartments is an 11-building, all-electric, 100% solar offset, Passive House development in Rotterdam, New York — a bedroom community to the adjacent state capital, Albany. This "eco-luxury" development targets professionals, families, and seniors.

Solara has above code insulation in the walls (~R27-R34) and in the roof (~R39-R50) and uses ductless mini splits for heating and cooling — one for each apartment and hallway.

Figure 14: Aerial view of the Solara Luxury Apartments.

Solara has a unique domestic hot water (DHW) design — it uses both solar thermal heating and an air-to-water heat pump as a back-up system during the winter months. Peter Skinner (E2G Solar LLC) is an advanced solar designer with over a decade in the field and is the co-author of Solar Hot Water Fundamentals — a textbook for SHW designers and installers. The Solara development has allowed him to experiment and iteratively improve his cold climate water heating designs, thanks to a supportive client and from collecting a great deal of performance data. In addition to just efficient hot water heating equipment, the hot water distribution was carefully designed to save both energy and water. (Designed by both Peter Skinner with mentorship from Gary Klein, a leading DHW researcher and plumbing designer). The distribution network design assures hot water arrival times in less than 15 seconds with sufficient pressure for excellent shower experience (despite low municipal pressures) and very low recirculation losses.

Table 9: Solara Apartments building specifications.

HVAC	One single head mini split per apartment and one per corridor ERVs for each apartment and each corridor
DHW	Solar thermal with heat pump water heater back up
Cooking	Electric
Envelope	Windows: Paradigm double pane Wall: Closed cell spray foam in walls (3-4 inches) with 1-inch Polyiso ZIP sheathing (R 26.6-33.6) Roof: 6-8-inch Polyiso boards on top of sheathing (R 39.2-50.4)

The lessons learned in the Solara Luxury Apartments project was that efficient plumbing reduces costs, solar thermal hot water systems are beneficial, and that equipment efficiency drops in cold climates. The efficient plumbing design and fixtures at Solara allow the 24 apartments in each building to be supported with just a 2–3-ton (24-36 kBTU/hr.) air-to-water heat pump in winter months, and a modest 14 panel solar thermal array for spring, summer, and fall. The heat pump cost Pete about $10,000 to install — just $416 per apartment because of all the efficiency measures. Solara's low-flow fixtures and 3/8" twig delivery piping uses significantly less hot water and delivers it much faster than standard designs, while reducing heating loads enough to save heat pump, solar array and hot water storage costs.

A large and highly insulated (1200 gallon) solar thermal heat vault acts as a multiday thermal battery. The recirculation loop temperature management system only operates when the trunk lines fall below a minimal temperature and only for a few minutes per recirculation loop. Pete is paid to provide these solar energy services and maintains the system regularly for optimum performance. In spring, summer and fall a 14-panel solar hot water system serves as the primary hot water heat source, nearly eliminating water heating bills from May through October. The 14 flat panels per building drain back to the basement to a 1200-gallon tank with heat exchanger coils suspended inside. Even on a sunny day in November, this system can collect the heat needed to serve the tenants for 1-2 days.

Figure 15: Pete Skinner with the Solara heat pumps.

When first installed, the 1.5 gal/min showers did not work as expected. The problem was traced to the shower valve body, whose internal bore hole was too small. Pete resolved the problems by installing different **Neoperl** showerhead inserts and will substitute better showerheads in the next phase. After testing numerous brands in a custom lab setting at various pressures, Pete and Gary were able to identify brands that performed much better, including **Moen**, **Kohler,** and **Delta Classic**. Showerheads are tested at 80 psi, which is the highest pressure allowed to be delivered to a building, but not at real world pressures of 26-60 psi. The showerhead brands mentioned created half as much pressure drop compared to other brands.

After seeing two air-source heat pump brands provide lower than rated hot water delivery during cold weather, Peter has tested three different "cold-climate" air-to-water heat pumps and found that some drop their production by half in 10-degree weather, while others do better in colder weather. The **Arctic**, a Canadian brand, and the **Chilltrix**, an American brand in Virginia, maintained better efficiency and higher heat output at 10-degree weather. Both products use R410A refrigerant, which generally does not get water hotter than 130°F degrees (**Aermec** goes to 140F), so to keep the water free of diseases such as Legionella, these heat pumps must be paired with electric resistance tanks to regularly bump up the water temperatures to setpoints between 130-140 degrees.

Front Flats, Philadelphia, Pennsylvania

Onion Flats LLC is a development team of three brothers who respectively lead the architecture, construction and sales of Zero Net Energy, Passive House certified housing in Philadelphia and nearby towns. Not only are their buildings examples of Best Practices at work, but their pricing is the same as standard construction in Philadelphia at just $170 per square foot due to their integrated design and construction process, and cost savings from standardization of Passive House in their developments.

Front Flats in Philadelphia, PA, is covered with solar panels on the South, West, and East sides as well as the roof, powering four floors of market rate residences, ground floor commercial spaces and electric car parking spaces while still providing a rooftop garden. The solar array panels are bi-facial, meaning they can collect energy from the sun from both faces of the panel, and the total array is predicted to produce 20% more energy than the building consumes and has a total size of 172 kW.[23]

The building components include an airtight envelope, high performance double paned windows, a **Minotair** HVAC system that combines heating, cooling, dehumidification, and fresh air ventilation into one unit, and **Rheem** heat pump water heaters — two for every four apartments. The **Minotair** system is particularly innovative because it provides whole house ventilation, whole house dehumidification (without heating), can have a MERV 15 air filter, can exhaust up to three bathrooms and the kitchen, as well as providing 8,700 BTU/hr of heating capacity with a COP 3.0 and 11,200 BTU/hr of cooling capacity at a COP 3.3, which is not typical for HRVs to have all these capabilities.

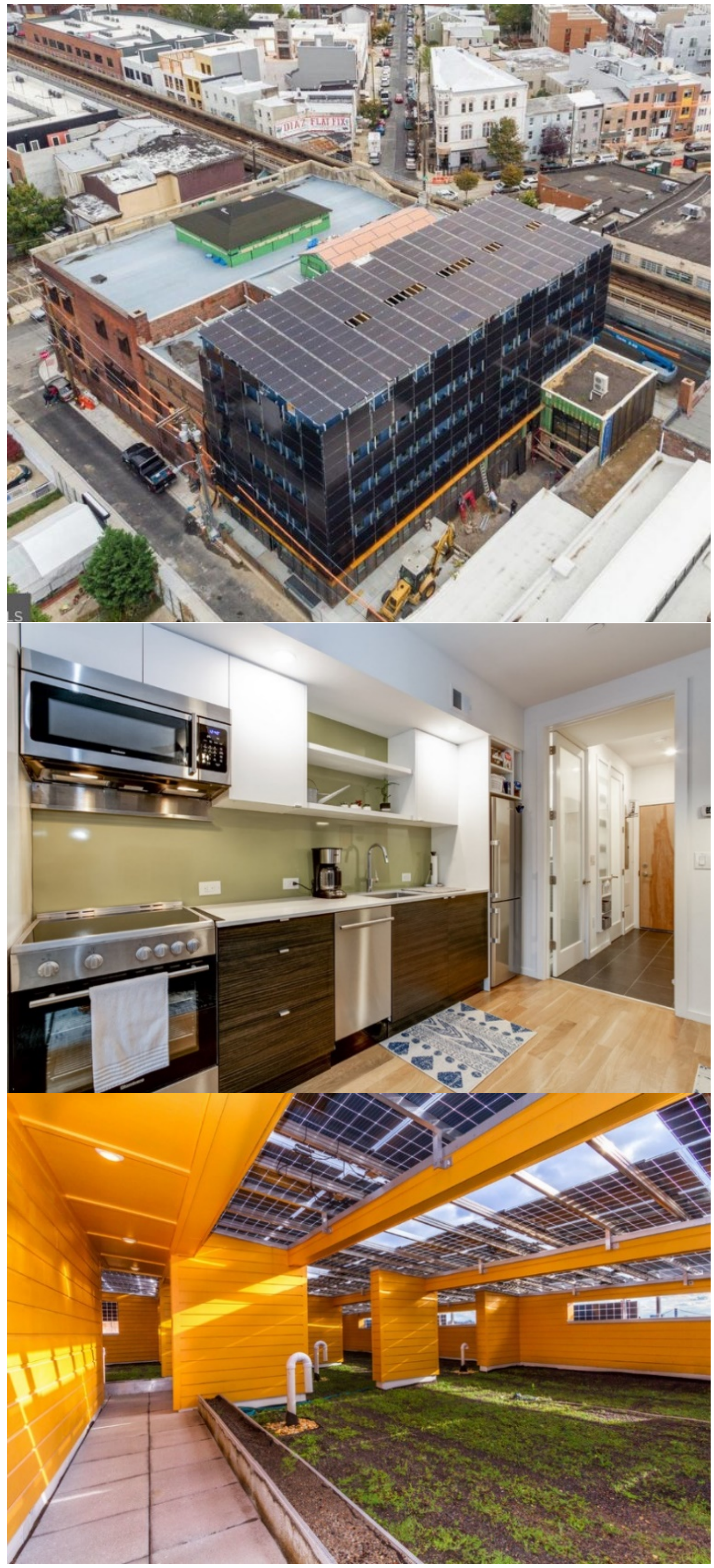


Figure 16: Aerial view of the solar-clad Front Flats, the kitchen with electric radiant range and solar-shaded rooftop garden.

Figure 16). The Front Flats DHW

plumbing design also takes energy efficiency a step further; the returning hot water is piped ***within*** the supply hot water pipe, to greatly reduce heat loss, a strategy known as "pipe-in-pipe" design.

There are numerous lessons learned for this project. The first, wall-mounted and rooftop canopy PV arrays are cost-effective and can provide shading benefits to the building and common spaces. The second, 80-gallon heat pump water heater tanks, plumbed in series with two tanks serving four apartments and distributed in vertical stacks with "pipe-in-pipe" design, are the least cost heat pump water heater design and highly efficient. (Instead of doing a larger, single centralized heat pump water heater system that serves all units). Lastly, Passive House design, once standardized for cost containment, is appropriate for affordable housing as well as market rate housing, although this project narrowly missed the official certification of LEED Platinum.

Table 10: Front flash building components.

HVAC	Minotair HRV and heat pump Heating capacity: 8,700 BTU/hr (COP 3.0) Cooling capacity: 11,200 BTU/hr (COP 3.3)
DHW	Rheem 80-gallon heat pump water heaters, one for every two apartments, pipe-in-pipe plumbing design
Cooking	Electric Radiant
Envelope	Walls: dense packed cellulose R33 Roof: dense packed cellulose R53 Windows: U-Value 0.2

R-951 Residence, Brooklyn, New York

The R-951 Residence, located in Brooklyn, is the first of its kind in New York City to achieve passive house and net-zero capable certifications.[24] The four-story 5,600 square foot residence includes three 1,500 square-foot 3-bedroom lofts, generating most of its power from the rooftop solar system that provides each residence with 4 kW of grid-tied electricity. This design achieves 75% reduction of typical building energy use for heating, cooling, and lighting which is then offset by 12.5 kW of solar. The building is well insulated and tightly sealed, therefore most of the heating and cooling needs are met with a **Zehnder** energy recovery ventilation system in each unit, which also filters the air, recovers moisture to manage indoor relative humidity, and will save up to 90% of space heating and cooling costs. Any additional heat needed is provided by a small Mitsubishi air source heat pump in each apartment and domestic hot water is provided with a **Stiebel Eltron** 80-gallon heat pump water heater in each unit, a stark contrast to the fossil fuel burning boilers that are typical in New York. Since the project met Passive House standards, particular attention was paid to the building envelope; it uses insulated concrete forms (Styrofoam blocks filled with cement), state-of-the art R-9 Tilt and Turn windows, air sealing (with **Pro Clima** tape and spray foam) and meticulous detailing to prevent thermal bridging, all to reach an ACH50 of 0.28. Other highlights that ensure tenant comfort are the daylighting, improved indoor air quality from not burning gas indoors and proper ERV ventilation, and an exceptionally quiet living space which is unique to the bustling city of Brooklyn.

Table 11: Building specifications for the R-951 Residence.

HVAC	Mitsubishi Air Source Heat Pumps (cooling capacity 34,400 BTU/hr, heating capacity 20,300 BTU/hr, 2.7 COP) Zehnder Comfoair 350 Energy Recovery System
DHW	80-gallon Stiebel Eltron Accelera 300 Heat Pump Water Heaters (3.2 Energy Factor)
Cooking	Electric Induction – All ENERGY STAR Appliances
Envelope	Walls: Insulated Concrete Forms R-21 Exterior Walls (front and rear): additional 4inches of Polyiso, total for the wall R-46 Windows: Shuco triple pane, Tilt and Turn R-9 Roof: R-59

The lessons learned on the R-951 project are that there are substantial savings that can be realized from not installing gas lines, boiler flues and related piping that can assist in offsetting the costs associated with the advanced envelope construction needed to meet Passive House standards.[25] On their next project, Architect Paul Castrucci said he would simplify wall construction to use less types of wall insulation (instead of using both spray foam and mineral wool in one wall, for example) and utilize more liquid-applied air-sealing to pass the tests for air leakage in between units by a higher margin.[25]

All-Electric Product Guides

Technology Background

This section covers everything one finds in a residence: space heating; domestic hot water; stoves; laundry drying; electric fireplaces; electric cars; electric car chargers; electric landscaping; and electric saunas, pools and hot tubs. Pricing and technical details are provided in the tables below images of leading brands. Be aware that new models come out frequently and old models are retired, and prices will vary from our findings — our apologies should the information be out of date.

A key technology in building electrification is the vapor compression cycle in an air conditioner, which can be reversed to also perform heating. This technology goes by many names, depending on the application: "refrigerators," "air conditioners," "heat pumps," "condensers," and "reverse chillers," to name a few. The history of refrigeration dates back to the 1550s, when saltpeter baths were first used to chill wine. Ice manufacturing was a booming business by the late 1700s, and the first true "refrigerator" using a vapor compression cycle was built to chill beer at the nation's largest brewery, S. Liebmann's Sons Brewery in Brooklyn, New York in 1870. Willis Carrier is credited with inventing the air conditioner in 1902 also in Brooklyn, NY, and by the 1920s residential refrigerators were common nation-wide. Products that could both heat and cool a home came on the market in the 1950s, now called "heat pumps."

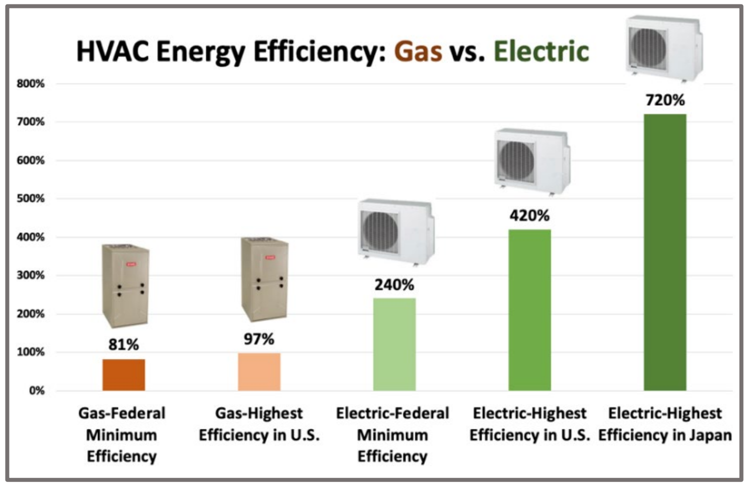


Figure 17: Air source heat pumps collect more energy from the air than they use to gather it. (Image by Redwood Energy)

Heat pumps can draw their energy from three main sources — the air, the ground and water — and this heat is then used to heat the air or water. The most common and flexible heat pumps are "air source," like that in your refrigerator or your air conditioner. Ground source heat pumps require drilling equipment but operate well in the winter. Water source are even less common, requiring a pond or similar source of water, unless it uses wastewater from a building. Sometimes, "Air to water heat pump" refers to a two-stage process, where a central air source heat pump collects heat or dissipates heat to heat or chill water, and then that water circulates through the building to radiators or hydronic floors, instead of being blown via heated air.

Figure 18: Air Source Heat Pumps can operate down to -31°F. [26]

Heat pumps can move heat from one substance to another so well because of the compression and expansion of fluids called refrigerants. There are many types of refrigerants, but the most common for heating and cooling are the Hydrofluorocarbons r410 and r134a which are newer versions of refrigerants like R22 but do not contribute to ozone depletion. However, the industry has been moving toward "natural" refrigerants like CO_2 (R744), Ammonia (R717) and Propane (R290) that do not deplete the ozone and contribute many orders of magnitude less to global warming.

Cold Climate Heat Pumps can now collect heat from outside air down to Arctic temperatures (-20°F)[27], where early models were limited to warmer climates. With the use of inverters, heat pumps can now accelerate their compressor pump so they can operate in below freezing temperatures. In addition to inverter technology, cold climate heat pumps have a heating element to defrost the outside unit to keep ice from forming on it.

Domestic Hot Water

The following section provides electric alternatives to gas water heaters for single family applications. The most common options are individual tank water heaters and on demand water heaters. Heat pump water heaters deliver hot water at high efficiencies and typically come with electric resistance back up for peak loads.

Large Central Heat Pump Water Heaters

Apartment buildings, hotels and large commercial facilities usually heat water in a central plant and plumb it throughout the building. These systems can range from 10 tons to 260 tons (1 ton = 12,000 Btu/hr) and like any central system they require careful design of the pumps, heat exchangers and storage tanks to optimize energy use and heat pump operation. The range of operating temperatures is important — each product has a different maximum output temperature, between 120°F and 180°F, and a minimum operating temperature between 5°F and 45°F before it switches off the heat pump and uses resistance to heat the water. Resistance heating, which is 100% efficient verses the heat pump which is 200-400% efficient should be minimized to get the maximum efficiency of heat pump water heaters. To achieve large temperature lifts (like 0°F to 185°F) multiple products can be used in series; for example the Colmac CxV's (low temp air source heat pump) in multi-pass to heat a glycol loop for the CxW (water source heat pump), a suggestion from Brian Culler of Colmac. With a three-phase power connection, the Transom Hatch[28] can deliver water temperatures as high as 180°F, through either placing multiple units in series (as many as 12) to create up to 24 stages, or through controlling flow within the unit or in the hydronic system design. Getting heat pumps to output 180°F degree water allows them to be a direct replacement for gas boilers in high temperature applications like hospitals, high rise apartments, universities, and more.

On the cost of large central heat pumps: "It is very difficult to get contractors to provide pricing for subsets of work within a larger scope, below is some of the best data we have to date— $1,359/Apt, an incremental cost of $600/apartment more than using a gas boiler, but the estimate does not include the savings from eliminating gas service, which can be $600-$1000/apartment." – ***Shawn Oram, Ecotope***

Large Central Heat Pump Water Heaters (240V-480V)

	IceAir CCHPD325, CCHPD650 	**Arctic** 060A 	**Nordic** ATW Series 	**Transom** Hatch HAP(064-240)W-(1,2) 	***Colmac*** CxV 
Description	Air source heat pump water heater	Air source heat pump water heater	Hydronic heating, fan coils for air-conditioning	Air source heat pump water heater	Air source heat pump water heater
Voltage (V)	230 / 3 Phase	240	208/230	230/208 and 3 phase	230/220

Ref. Type	R410a	R410a	R410a		R134a
Heat Pump Ambient Temp. Range (F)	**-13**	**-15**	**-7 – 120**	**-25 - 95**	**-4 – 120**
Power (W)	35,000 - 71,000	5500	1,190 – 2,500	9,900 – 40,000	4,900 – 6,300
Amps (A)	65 - 131	27.3	15 – 30	Max 67.8 - 238	36.8
Heating Cap. (Btu/hr)	290,000 – 566,000	68,000	22,700 – 59,100	64,000 – 524,000	31,200 – 77,900
Cooling Cap. (Btu/hr)	324,000 to 641,000	52,000	17,400	-	17,300 – 60,700
Heating (COP)	2.4	3.6	1.38 - 4.94	1.75 - 3.57	1.8 – 3.7
Cooling (COP)	4.4	2.50	1.57 - 5.84	-	1.0 – 2.9

Best Practices for Heat Pumps Central Domestic Hot Water Systems

Using heat pumps to provide space cooling dates to the 1920s, for space heating to the 1940s, but using compressors to heat domestic hot water for cafeterias, apartment complexes, dairies[29] and other large uses dates only to the 1970s and has advanced further in Asia where efficiency is more valued. Consequently, there is less familiarity among North American designers of both the products and practice of designing commercial hot water systems using heat pumps. Below is helpful guidance from the engineers at Ecotope of Seattle, the most experienced designers (25 systems so far) of central domestic hot water heat pumps in North America.

1. ***Heat pumps are not boilers***. Do not oversize the central heat pump for faster recovery, which leads to both higher construction costs and equipment failure. Instead use a series of dispatchable 5-15-ton heat pumps, rather than one larger (e.g., 60 ton) heat pump and favor hot water storage over hot water production.
2. When designing hot water systems, ***split the pipe recirculation heat loss load from the use load***. Temperature improvement of recirculating water is ideal for “multi-pass” heat pumps that handle 110°F incoming water (e.g., Aermec, Daiken) and perform 10°F temperature bump-ups, while meeting peak loads is best done with a “single pass” heat pump (e.g. Sanden, Colmac) that uses cold incoming water, not recirc water, to efficiently lift temperatures from 50°F to 150°F.
3. ***Install “heat traps”*** on both hot and cold-water sides of storage tanks to prevent migration and mixing.
4. ***Reduce pipe surface area*** to greatest extent possible. Insulate remaining pipes with 1”-4” of foam, depending on space availability. Insulate tanks to at least R-19, same as an outside wall, due to the even more extreme heat loss than found in a wall.
5. ***Design diagnostics into crucial points in the heat plant and distribution system***—electrical gauges to measure power quality, temperature gauges to monitor heat gain and loss, and control valves on the discharge side of pumps to measure pump flow
6. ***Provide redundancy in heat pumps and choose electric resistance storage tanks*** for a durable, dependable design for the eventuality that system components need improvement.
7. ***Consider adding drain line heat recovery*** to save energy while improving the hot water delivery capacity. This is a simple heat exchanger to transfer heat from the drain line to the incoming cold-water input to the water heater.

Figure 19: Ecotope Case Study "RCC" system for 194-unit Multifamily building, using best practices in central heat pumps for domestic hot water, from ACEEE presentation by Shawn Oram. [30]

Individual Tank Heat Pump Water Heaters

Typical electric water heaters that use electric resistance are not shown due to their minimal efficiency. The products shown collect 2.4 – 3.8 units of heat for every one unit of electricity powering the air source heat pump and provide 30-80 gallons of water storage. Some have a 4,000 BTU compressor integrated on top of the tank, others use a 12,000-36,000 BTU separate compressor outside that produces more BTUs at a higher efficiency. These models can be used as either serving one dwelling unit or can be combined in a distributed central plant to feed multiple units. Installing these units indoors especially in basements can provide dehumidification as well as avoid low ambient temperatures. Another way to think of it is they provide free hot water and dehumidification for half the year by offsetting a small amount of cooling load. New systems using CO_2 as a refrigerant (R744) can handle brutal winter climates.


Figure 20: Jane Fisher decided to install an energy saving heat pump water heater at her investment property in Melbourne. [31]

Heat Pump Water Heaters (240V)

	Eco2 Systems	**Steilbel Eltron** Accelera	**Rheem** Prestige Hybrid	**AO Smith** Voltex Hybrid	**Bradford White** AeroTherm
Manufacturer and Product Image					
Description	Large Volume Cold Climate CO2 Refrigerant	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance	Hybrid: Heat Pump and Resistance
Gallons	43, 83	58, 80	50, 65, 80	50, 66, 80	50, 80
Voltage (V)	208/230	220/240	208/240	208/240	208/240
Dimension (in)	27.5H x 35W x 11D	60H x 27Diam.	74H x 24Diam.	69H x 27Diam.	71H x 25Diam.
Ref. Type	R744 (CO2)	R134a	R134a	R134a	R134a
Heat Pump Ambient Temp. Range (F)	**-30 – 110 (cold climate)**	42 – 108 / 6 – 42*	37 – 145*	45 – 109*	35 – 120*
Power (W)	3,120	650 - 1500		4,500	550 – 4,500
Max Amps (A)	13	15	15 – 30	30	30
Heating (Btu/hr)	15,400	5,800	4,200	-	-
Heating (COP)	5.0	-	-	-	-
Energy Factor	3.09 – 3.84	3.05 – 3.39	3.55 – 3.70	3.06 – 3.61	2.40 – 3.39
Price ($)	$ 3,400	$ 2,300-2,600	$ 1,200-1,400-1,700	$ 1,400-1,500-1,900	$ 1,400-1,600

* No outdoor temperature limit with electric resistance back up.

Retrofit Ready Heat Pump Water Heaters (120V)

There has been a market demand for heat pump water heaters that are "retrofit ready" meaning, they can plug into a 120V typical electrical socket, to rapidly electrify water heating. Both Rheem and GE have announced they will be releasing retrofit ready heat pump water heaters to the U.S. soon.

	GE GeoSpring	**Rheem** Prestige Hybrid
		
Description	Heat Pump Only	Heat Pump Only
Gallons	40, 50	40
Voltage (V)	120V	120V
Notes	More Specifications Coming Soon	More Specifications Coming Soon

Product Highlight – Eco2 Heat Pump Water Heater

The Eco2 uses CO_2 as a refrigerant (which does not contribute to global warming, like other typically used refrigerants) and allows the heat pump to have no "hard stop" of operation even at very low outdoor air temperatures.[32] At low outdoor air (-15°F) and low inlet water temperatures (Figure below) it can make hot water up to 145°F, and it is still more efficient than the top-of-the-line natural gas hot water heater (COP of 1.9 vs. COP of 0.95). At warm outdoor air temperatures (above 70°F) the COP, or effeciency of the Eco2 heat pump water heater, increases to above a 5.0 COP, where a comparable natural gas water heater is still at a 0.95 COP.

"As temperatures drop to -30°F and below ***"there is no hard stop on the unit operation"*** of the Eco2 heat pump water heater.

- John Miles, Co-Owner of Eco2 Systems

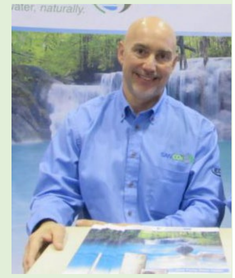


Figure 21: The Eco2 heat pump water heater compressor working outside in 5°F (-15°C) weather. [33]

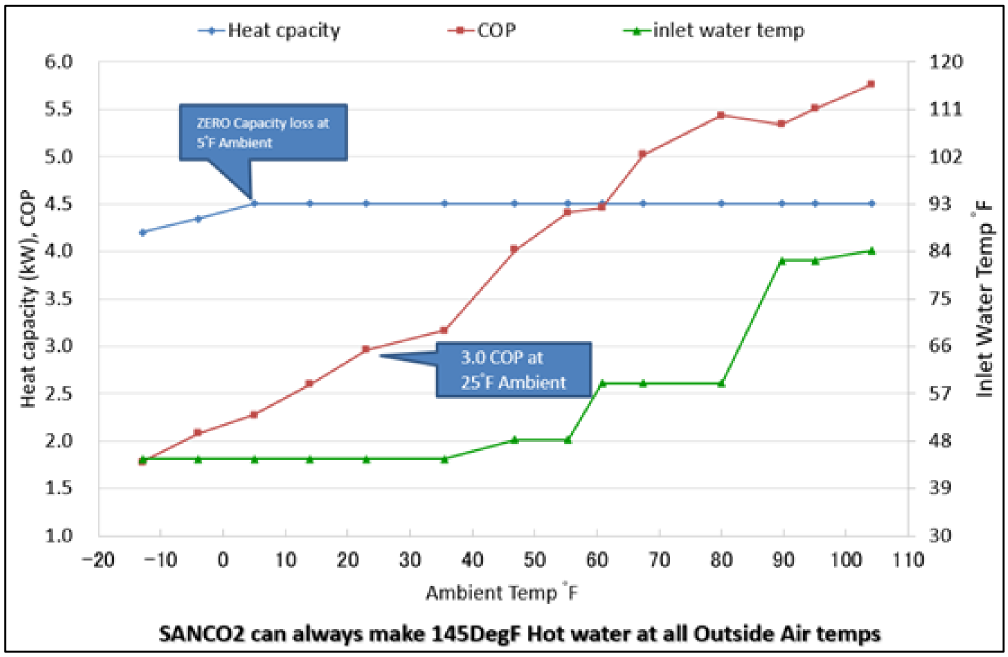


Figure 22: Eco2 heat pump water heater heating capacity, COP and inlet water temperatures at various ambient air temperatures.[34]

On-Demand Water Heaters (120V and 240V)

Electric resistance water heaters are best used where hot water is needed in small amounts or when a project requires strict voltage limitations. Tankless water heaters can be used in a bathroom, or a 120sf tiny house that has no room for a 50-gallon tank or that is not sharing water system with other tiny homes. Electric resistance uses 2-4 times more energy than a heat pump but can be the right size for the right demand and they are helpful when there is no 220V electricity available. The 2 to 7-gallon tanks on the market use 120V, while anything larger uses 240V for more heating capability.

Small Demand and Low Power Applications (120V)

Manufacturer and Product Image	**Stiebel Eltron** SHC Series 	**Bosch Tronic** 3000 Series 	**Stiebel Eltron** Mini-E Series 

Description	Mini tank, Point of use	Mini tank, Point of use	Tankless, Point of use
Gallons	6, 4, 2.7	7, 4, 2.7	0.21 (gpm)
Voltage (V)	110/120	120	120/110
Dimension (in)	20H x 15W x 15D	17H x 17W x 14D	6H x 7W x 3D
Power (W)	1,300	1,440	1,800
Max Amps (A)	11.3	12	15
Heating (COP)	0.98	0.98	0.98
Price ($)	$ 230	$ 210	$ 160

Hybrid Heat Pump and Electric Resistance On-Demand Water Heaters

One specialty product is a hybrid heat pump and electric resistance back up water heater by Nulite. This product is meant to replace on-demand gas water heater systems and are more efficient a typical electric resistance and gas on-demand water heaters. Created in China, they are now available in the United States.

Manufacturer and Product Image	**Nulite** NERS-FR1.5F 	**Nulite** NE-BZ2/W200 
Description	Hybrid Heat Pump with Resistance	DC Inverter Heat Pump Water Heater
Gallons	18.5 (70L)	53 (200L)
Voltage (V)	220 @ 50 Hz	220V @ 50 Hz
Ref. Type	R134A	R410A
Ambient Temp. Range (F)	**5 – 68 (cold climate)**	**-13 – 118 (cold climate)**
Power (W)	860 – 1500	5,000
Max Amps (A)	Pending	20
Heating (Btu/hr)	12,500	27,000
Heating (COP)	1.36 - 5.34	Pending, Approx. 5.4
Energy Factor	Pending	Pending
Price ($)	UL Certification Pending	UL Certification Pending

Heating, Ventilation and Air Conditioning (HVAC)

The following section gives an overview of heating and cooling electric systems that are used in single-family and multifamily buildings. The sample of heat pumps shown are in three major categories – air source, geothermal, and hydronic. They range in size from 9,000 BTU/hr to 600,000 BTU/hr and include central heat pumps, mini-split heat pumps, packaged terminal heat pump, vertical terminal heat pumps, "all-in-one" HRV heat pumps, geothermal heat pumps, and hydronic heat pumps.

Resources for Finding HVAC Products

- Air-Conditioning, Heating and Refrigeration Institute (AHRI) Directory of Certified Product Performance https://www.ahridirectory.org/Search/SearchHome
- Northeast Energy Efficiency Partnerships (NEEA) - Cold Climate Air Source Heat Pump List https://neep-ashp-prod.herokuapp.com/#!/product_list/
- ENERGY STAR Product Finder https://www.energystar.gov/productfinder/

Air Source Heat Pumps (Air-to-Air)

Using a reversible air conditioner — a "heat pump" — to heat people's homes began in the 1930s, grew in popularity in the 1950s when they became smaller and more affordable, and has grown exponentially world-wide. Air source heat pumps that heat air do so with fan coils that may be mounted on the wall or ceiling or hidden in the ceiling or a closet and connected to ducts. Starting in 2001, computers began to be added to heat pumps — these small computers calculate in real-time the heat available outdoors vs. the heat requested indoors and speed up the internal parts to collect more heat as the outdoor temperature drops, even down to — 31°F/-35°C. They have the side benefit of being much quieter than single-speed heat pumps. Heat pumps with these computerized controls are often advertised as having "inverter drives," "variable speed" or "variable refrigerant flow," phrases which all have the same meaning.

Variable Refrigerant Flow Heat Pumps (240V)
VRF systems are split heat pumps that transport heat through a building with refrigerant lines, the larger version of ductless mini-split systems. As such, they are typically used in commercial buildings or for community spaces in multifamily developments and can be useful in retrofits of mid-sized buildings when space for ducting is limited.

	Mitsubishi City Multi Y-Series	**York** Gen II Heat Recovery	**Carrier** VRF 38VMH	**Daikin** VRV IV Heat Pump
Manufacturer and Product Image				
Voltage (V)	208/230	208/230V - 460V	208/230V	208/230V - 460V
Dimension (ft)	5.4H x 5.7W x 2.4D	66 ¼ x (38-3/8, 48-5/8, 64) x 30-1/2	64-3/8 x 52-¾ x 31-7/64	(66-11/16 x 36-11/16 x 30-3/16) - (66-11/16 x 48-7/8 x 30-3/16)
Ref. Type	410A	-	R410a	
Ambient Temp. Range (H/C) (F)	**-13 – 60 / 12 – 115 (cold climate)**	**-13 – 122 (cold climate)**	**-5 – 125 (cold climate)**	**-4 – 122 (cold climate)**
Power (W)	5,700 - 12,200	-	-	-
Max Amps (A)	23 - 53	-	-	-
Heating Cap. (Btu/hr)	80,000 – 405,000	81,000 - 216,000	80,000 – 108,000	73,000 - 435,000
Cooling Cap. (Btu/hr)	72,000 – 360,000	72,000 - 192,000	72,000 - 96,000	73,000 - 372,000
Heating (COP)	3.56 – 4.22	2.05 - 4.25	-	-
Cooling (COP)	3.40 – 4.16	-	-	-

Central Ducted Heat Pumps (240V)
Ducted heat pump and air conditioning systems are usually driven by a central compressor that pumps air through ducts to vents in different areas throughout the building. These systems pair an outdoor air to air heat pump unit with an indoor evaporator coil and air handler unit.

Manufacturer and Product Image	**York** YZH02412C 	**Goodman** GSZC180481C 	**Daikin** DZ14SA0483 	**Carrier** Infinity 25VNA036A003 
Dimension (in) (WxDxH)	42 x 23 x 34	35 x 35 x 38	29 x 29 x 34	35 x 28 x 44
Crankcase Heater	No	Yes, with switch	Factory-installed	Internal, Factory Installed
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-10 – 115 (cold climate)**	**-5 – 115 (cold climate)**	**-10 – 65 (cold climate)**	**-4 – 68 (cold climate)**
Power (W)	2,500 – 3,412	4,830 – 4,840	3300	1,050 – 1,240
Heating Capacity (Btu/hr)	18,000 - 59,000	22,000 – 59,500	44,500	25,000
Cooling Cap. (Btu/hr)	19,000 – 58,000	23,000 – 56,500	45,000	36,000
Heating (COP)	2 -4	1.47 – 6.77	3.95	2.3 - 4
Cooling (COP)	4 – 4.4	3.66 – 4.10	4.1	4 – 4.4
Price ($)	$ 2,000	$ 2,500	$ 2,000	$ 3,200

Energy Consequences of Uncontrolled Crank Case Heaters

Traditional ducted Heat Pump and Air Conditioner Compressors are often heated with a crank case heater (or sump heater), which keeps the lubricant warm enough to not mix with refrigerant – preventing it from becoming "milky" and resulting in a noisy, inefficient heat pump. These can use a significant amount of electricity if uncontrolled (e.g. 100W on 24/7/365 becomes **876 kWh/year which can double the energy use of a smaller home**), but can be designed to use very little energy, and only when needed. Some HVAC heat pumps do not use them at all due to different lubricants or modified design. One should consider this non-rated, but real, energy use when choosing a heat pump.

Figure 23: "Belly Band" crankcase heater (heating wire wrapped around compressor).

Figure 24: Insertion crankcase heater (heating element inside compressor).

Many manufacturers have devised strategies to avoid or reduce the use of a crank case heater:

- Using lubricant that does not mix with refrigerant
- A recycling pump that stores refrigerant away from the compressor lubricant during shut down
- Temperature sensors that only turn on the crank case heater when the refrigerant gases are approaching liquid state and could mix with lubricant

While crank case heaters are not (yet) clearly identified in product specification sheets, asking for information from the Contractor or their Distributor will clarify whether you may have a heat pump that performs as advertised or an unidentified, potentially large "phantom load."

Mini-Split Heat Pumps (240V)

Mini-Split systems are comprised of a compressor outside the building and a fan inside the building. Mini split systems can also have many fans inside the building, commonly referred to as multi split systems, where one outside unit serves multiple fans or zones inside the building. Having multiple zones in the building allows for a more controlled, versatile arrangement of installations and temperature settings compared to a typical split HVAC system. Zones can be at different temperature settings while still being served by one outside unit. Multi/mini-split systems can be ductless (where refrigerant lines move heat around the building) or they can have mini ducts where air is moved around the building. Having no ducts prevents duct leakage energy losses but having many refrigerant lines running through the building can cause problems if they leak. In general, mini/multi split systems are more efficient than typical HVAC systems. No ducting also has an advantage because of reduced fan loads.

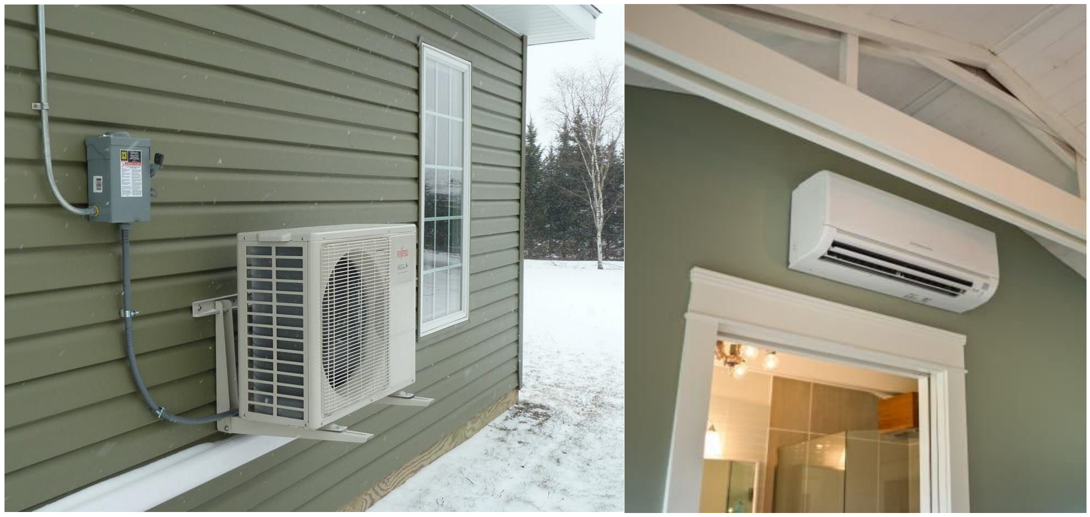


Figure 23: An example of a ductless mini-split heat pump outdoor compressor mounted to stay above the snow and a wall-mounted indoor fan coil.[35]

Ductless Mini-Split Heat Pumps (120V)

Interior Wall-Mounted Fan Coil 	**Carrier** 38MAR 	**GE** Caliber Series AS12CRA 	**Mitsubishi** MZ-JP12WA 	**Haier** 
Description	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil
Dimension (in) (HxWxD)	32 x 21 x 13	21 x 31 x 10	22 x 32 x 11	28 x 35 x 14
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-13 - 122**	**-4 - 115**	**-4 - 115**	**-4 – 115**
Power (W)	1,725	-	800 – 1,300	2,100
Max Amps (A)	15	-	11.8	18
Heating Cap. (Btu/hr)	12,000	12,000	12,200	16,000
Cooling Cap. (Btu/hr)	12,000	12,000	12,000	12,000
Heating (COP)	2.03 - 3.80	2.92	2.9	3.2
Cooling (COP)	-	2.92	2.9	3.75
Price ($)	$2400	$860	$1200	-

Ductless Mini-Split Heat Pumps (240V)

Interior Wall-Mounted Fan Coil 	**HAIER** Arctic Next Gen 	**Fujitsu** Halcyon Series 	**Mitsubishi** HyperCore FH50 	**MrCool** MDUO180(24-60) 	**LG**[36] Multi F MAX LGRED 
Description	1 Indoor Fan Coil	1 – 4 indoor Fan Coils	1 – 4 indoor Fan Coils	Pre-charged, 2 - 5 Fan Coils	2 - 5 Fan Coils
Dimension (in) (HxWxD)	39 x 38 x 14	39 x 38 x 14	36 x 9 x 12	56 x 38 x 13	54 x 24 x 15
Ref. Type	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-31 / 95**	**-15 – 75 / 14 – 115**	**-13 / 115**	**-22 / 110**	**-13 – 64 / 14 – 118**
Power (W)	230 – 2,160	1,330 – 2,700	1,380 – 1,480	10,900 – 30,700	970 – 6,020
Max Amps (A)		16.4 - 26	13.6	10,900 – 30,700	22.96
Heating Cap. (Btu/hr)	23,000	9,000 – 36,400	10,900 – 30,700	24,000 – 54,000	15,840 – 61,000
Cooling Cap. (Btu/hr)	14,000	9,000 – 35,200	8,500 – 26,600	24,000 – 54,000	14,400 – 58,000
Heating (COP)	1.94 - 4.21	3.60 – 4.04	3.07 - 4.85	3.65	3.4
Cooling (COP)	2.74 - 4.46	3.52 – 3.60	3.31 – 4.11	4.12	4.1
Price ($)	$1,900	$ 2,000 - $5,000	$2,000 - $3,500	$3,000	$2,400 – 5,100

Ducted Mini-Split Heat Pumps (240V)

Attic Fan Coil and Ductwork 	**Senville** SENA/18HF/ID 	**Haier** Arctic Multi Series 4U36EH2VHA 	**Mitsubishi** MXZ3C24NAHZ2 	**Gree** MULTI18HP230V1BO 
Indoor Unit Dimension (in)	34.7 x 28.5 x 8.27	41 x 28 x 10	37.4 x 16.4	35.4 x 7.9 x 24.2
Outdoor Unit Dimension (in)	33.3 x 14.3 x 27.64	33 x 37 x 13	41.3 x 37.4 x 13.0	38.0 x 27.6 x 15.6
Ref. Type	R410A	R410A	R410A	R410A
Ambient Temp. Range (F)	**-22 (cold climate)**	**-15 - 115F**	**-13 – 115 (cold climate)**	**-4 – 118 (cold climate)**
Max Amps (A)	25	30	40	25
Heating Cap. (Btu/hr)	18,000	6,100 – 36,000	25,000	19,000
Cooling Cap. (Btu/hr)	17,000	5,000 – 34,400	22,000	18,000
Heating (COP)	3.0	3.1	2.6	2.6
Cooling (COP)	4.2	3.7	4.5	4.1
Per Indoor Unit Piping Length (ft)	98	83	82	65

Price for Outdoor Unit ($)	$ 1,400 (includes 50 ft refrigerant line)	$3,400 (outdoor unit only)	$ 3,110 (no ducting or refrigerant lines)	$ 1,930 (no indoor units or refrigerant lines)

Attic Fan Coil and Ductwork 	**Pioneer** YN012GMFI22RPD 	**Mitsubishi** MXZ2C20NAHZ2 	**LG** LD127HV4 	**Fujitsu** 12RLFCD 
Indoor Unit Dim. (in)	27.5 x 17.8 x 7.9	16.4 x 37.4	7.5 x 27.6 x 38.3	7.8 x 27.6 x 24.4
Outdoor Unit Dim. (in) (HxWxD)	27.5 x 17.8 x 7.9	41.3 x 37.4 x 13.0	33.0 x 21.5 x 12.6	24.5 x 31.1 x 11.3
Ref. Type	R410A	R410A	R410A	R410A
Ambient Temp Range (F)	**-13 – 122 (cold climate)**	**-13 – 115 (cold climate)**	**-4 – 118 (cold climate)**	**-5 – 115 (cold climate)**
Max Amps (A)	15	29.5	15	15
Heating Cap. (Btu/hr)	12,000	13,700	16,000	16,000
Cooling Cap. (Btu/hr)	12,000	18,000	11,600	12,000
Heating (COP)	3.37	2.79	3.1	3.4
Cooling (COP)	4.35	3.6	4.18	4.2
Per Indoor Unit Piping Length (ft)	82	82	66	66
Price for Outdoor Unit	$ 1,200 (includes 25ft refrigerant lines)	$ 2,780 (no refrigerant lines)	$ 2,050 (no refrigerant lines)	$ 1,660 (no refrigerant lines)

The Complete Cost of Mini-Split Systems

The following section gives an overview of the costs associated with hiring a contractor to install ductless heat pumps. The first table show the pricing for leading manufacturers for single-head and multi-head systems. Below is a 2019 interview with Jonathan Moscatello of the Heat Pump Store in Portland, Oregon, a description of the mark up on heat pump prices, and a description of costs for short ducted or mini-duct systems.

Single-Head					
	9k BTU	**12k BTU**	**15k BTU**	**18k BTU**	**24k BTU**
Daikin	$4,200	$4,450	$5,000	n/a	n/a
LG	$4,400	$4,500	$4,800	$5,000	$5,200
Panasonic	$4,400	$4,600	$5,800	n/a	n/a
Fujitsu	$4,600	$4,800	$5,100	$5,700	$5,900
Mitsubishi	$4,900	$5,400	$5,800	$6,100	$6,400

Multi-Head				
	2 Zone	**3 Zone**	**4 Zone**	**5 Zone**
Daikin	$6,800[a]	$8,500[a]	$10,500[a]	n/a
LG	$6,200[a]	$7,800[a]	$9,400[a]	n/a
Panasonic	$6,200	$7,100	$8,100	$10,200
Fujitsu	$7,400[a]	$9,000[a]	$11,200[a]	$12,500
Mitsubishi	$8,500[a]	$10,500[a]	$12,900[a]	$15,500[a]

- Multifamily installations, where the labor is onsite all day and able to accomplish 4-6 installations, cost ~30% less
- Indoor units involving simple installation method, the outdoor and indoor unit sharing an exterior wall with 15' of interconnecting line sets and electrical
- Indoor unit is of the high-wall mounted type
- $500 increase per indoor unit is typical when the refrigerant line set length increases to 25’ or longer to cover the additional labor and materials to add refrigerant to the system
- Up to $1,000 increase per indoor unit when the indoor unit is located on an interior wall, necessitating that the refrigerant line set be installed through an attic or crawlspace
- [a] Indicates “cold climate” model

Interview on Heat Pump Pricing with Jonathan Moscatello of the Heat Pump Store in Portland, Oregon

The following section summarizes the correspondence between Sean Armstrong of Redwood Energy and Jonathan Moscatello of the Heat Pump Store in Portland, Oregon. Jonathan had just returned from China, where he has direct import relationships for ductless mini-split heat pumps, with decades in the business.

A lot of people are not clear about how heat pumps are sold in the market. Could you explain to us?

Sure, it's not that complicated, but it’s true that most people aren’t exactly sure how it works. The process starts with the Manufacturer — they sell to Distributors. I don't know what the Manufacturer pricing is, and generally it's not possible to buy directly from the Manufacturer. When you are a Contractor who wants to install a heat pump, you buy from the Distributor. Then you sell it to the Client, and at each step there is a markup of 25 to 50%.

If the contractor is fair and the labor is well-trained and fairly paid, what is the total cost of installing a ductless mini split with one fan coil?

The lowest cost for a one ton, with one fan coil, that you'll see where someone can stay in business is $4,200 to do an individual house. For a 2-ton, $5,500 is the lowest price you would see. In multifamily, where a contractor could have a property owner or a general paying for electrical AND where the installers could be onsite for a week (operating in a highly productive installation, 4 to 6 systems per day) — we regularly see $3,000 per system installation — about 30% less than an individual home. I did this business for several years, and contractors take a lot of risks and work hard in difficult work environments.

How much does it cost to buy just the materials for a 1-ton mini split heat pump?

What the Contractor pays from the Distributor is $800 to $1,400 a ton, with the average around $1,200. Mitsubishi is an example of a $1,400 per ton product, while $1,200 a ton is found in products from Daikin, Panasonic, LG, and Aurora. What the contractor charges a client is 40% to 50% more than their price. So, $800-$1400 to the Contractor is $1100-$2100 to the Client, plus labor and additional materials.

Can you tell us about the cost for buying and installing a heat pump with multi-zone system, where there are 2-5 fan coils scattered in different rooms?

Well, if a 1-ton mini-split cost about $1,200, a 1.5 ton with two fan coils cost $1,600 to $1,800, and a 2-ton compressor with three fan coils cost about $3,200. Of course, this is marked up 40%-50% when sold to a client. The inside fan coils each cost about $450, while the compressor goes up in cost at about $800/ton.

What about the Labor costs for installing a ductless mini split?

Labor is a constrained resource. For a full-time job, labor is paid $25 to $35 an hour, and sold to the client at $42 to $60 an hour. To install a 1-ton heat pump by market leading contractors takes 2 to 4 hours, and for contractors who do not typically install ductless systems — that same work takes 4 to 8 hours because of contractor inefficiency, likely due to their relative inexperience.

Cost Breakdown of Overhead Minisplit Heat Pumps

Pricing of ductless heat pump installations varies widely due in large part to the margin goals of the installation company involved. Typically, installation companies fall into three margin categories based on attributes relating to their overhead and size. Below is an example of marked up costs and the breakdown of overhead pricing.

Table 12: Example of "Marked Up Costs" Pricing Model of Simple Installation of a Single Zone System.

Labor	$300 (5 hours x $60 per hour)
Equipment	40% of sale price or $1,200 (and up to $2,400 depending on equipment)
Materials	Approximately 5% of sale, roughly $300
Subcontractor (electrical)	$600-1000
Permits	$100-150
Subtotal	$2,500 /.6 (40% Margin)
Total	$4,166

Table 13: Cost breakdown of how overhead costs for mini split heat pumps.

Margin Categories	Attributes related to Overhead and Size	Gross Profit
Low	Staff size: less than 5 Business location: Work out of home Years in business: "New Entrants", less than 5. Type of work: Almost all installation sales. Annual revenue: under $1.5 million.	25-35%
Medium	Staff size: 5 to 15 Business location: Small shop with limited office space. Years in business: 5 to 15. Type of work: installation, with limited service and improvement sales. Annual revenues: $1.5 to $3.5 million.	35-45%
High	Staff size: 15 to 50+ Business location: Professional office space, warehouse, loading dock. Years in business: over 15 years, often multi-generational. Type of work: Commercial and residential, installation, sales and service. Annual revenue: over $3.5 million	>45%

What can you tell us about the installation costs of Short Ducted Heat Pumps?

The pricing of so-called short run ducted mini-split systems varies widely, due in large part to the unique requirements of each installation. In general, the cost of equipment (only) used in short-run ducted split systems is comparable in cost to ductless split systems (when the comparing the cost of equipment per unit of BTU of output). The variability in installed cost comes from the labor and materials needed to install a ductwork system. In most installations, the ductwork system is newly installed instead of being reused from an older installation. In this way, the new ductwork system will satisfy the engineering requirements of the equipment and the space being conditioned.

The labor and materials involved in ductwork, insulation, air sealing and grills/registers should not be discounted. When ductwork is installed in attics and crawlspaces, the labor costs can increase when conditions make these spaces difficult to work in. When ductwork is installed within the conditioned space by attaching to the existing ceiling, there will be additional costs to install a "drop ceiling" to hide the ductwork. Many installers have found that when pricing short-run ducted systems, the ductwork materials can cost much more than the wholesale cost of the equipment.

Given all the variability in labor and materials required to install a short-run ducted split system, most contractors price each installation as the opportunity arises. They do this by estimating the labor hours required in the prospective job, ask their distribution partner to provide a quote for all the materials and equipment needed, ask subcontractors for a quote, and finally enter all these costs into a spreadsheet whereby they apply a mark-up to satisfy their company's margin goals.

This method of marking up all the unique costs has many benefits to the installation company; it provides the installers with a materials and equipment list, and the company with a proforma model that they can manage by within should the company win the job. However, this pricing system doesn't provide government and trusted energy provider programs with any simple pricing model to use.

Packaged Terminal Heat Pumps (240V and 120V)

PTACs and PTHPs are all-in-one HVAC units that are used to heat and cool 1 to 3 rooms. These types of units are ductless and can be hung from a wall and ducted through (e.g. Innova, Sakura), mounted in a window or placed into a cutout in the wall. Packaged units deliver heating or cooling directly to the space, avoiding energy losses from ductwork but introducing potential leaks around the product if it is not sealed.

Packaged Terminal Heat Pumps (120V)

	Innova HPAC 2.0 	**Olimpia** Maestro 	**Frigidaire** FFRH0822Q1 	**Gree** 26TTW09HP115V1A 
Description	Twin ducts through the wall, 8-inch air outlets, resistance back up	Twin ducts through the wall, dehumidification	Heat pump with Resistance	Heat pump with Resistance
Dimension (in)	1.8H x 3.3W x 0.5D	-	15H X 22W x 23D	15H x 26W x 16D
Ref. Type	R410a	R410a	R410a	R410a
Min. Heat Pump Operating Temp (F)	**-14 (cold climate)**	**5 (cold climate)**	40*	29*
Power (W)	545 – 730	830-850	780 – 1,290	830 – 1,150
Heating Capacity (Btu/hr)	3,100 - 10,000	10,600 (Heat Pump only)	7,000 (HP) 3,500 (ER)	6,600 (HP) 3,900 (ER)
Cooling Cap. (Btu/hr)	2,600 - 10,000	11,600	8,000	9,000
Heating (COP)	2.84 – 3.22	3.8	2.63	3
Cooling (COP)	3.12 – 3.28	3.8	2.87	2.87
Price ($)	$1950	$1700-$2300	$ 770	$ 840

*ER = electric resistance, HP = heat pump, *No low cut off temperature when using ER

Packaged Terminal Heat Pumps (240V)

	Ice Air (RSXC(09,13,18) 	**LG** LP(073,093,123,153) 	**Innova** SK92 	**Gree** W(07,09,12) 
Description	Theoretical lower limit of –25F, customizable shell	Heat Pump with electric resistance	Twin ducts through the wall, 8-inch air outlets, resistance back up	Heat pump with electric resistance, dehumidification
Dimension (in)	16H x 42W	16H x 42W x 21D in	16H x 26W x 27D	15H x 26W x 16D
Ref. Type	-	R410a	R410a	R410a
Heat Pump Operating Temp (F)	**-25, -5 – 95 (cold climate)**	**-4 - 75 / 54 – 115 (cold climate)**	**5 (cold climate)**	29*
Power (W)	1,200; 1,750; 2,150	2,300 - 4,700	3,060	680 – 3,500
Amps (A)	5.9, 8.5, 10.4	15,20, 30-amp cord	15.7	3.0 – 15.2
Heating Capacity (Btu/hr)	10,200 – 17,300	6200- 13,400	2,600 – 13,900 17,300 (with ER)	3,900 – 11,000 (ER) 6,600 – 11,400 (HP)
Cooling Cap. (Btu/hr)	9,200 – 18,000	7,100 – 14,900	3,100 – 10,500	7,200 – 11,700
Heating (COP)	3.0 - 3.6	3.1 – 3.5	2.6 - 2.9	2.9 – 3.1
Cooling (COP)	2.9 - 3.5	3.28 – 3.90	2.63 – 2.93	2.81 – 3.11
Price ($)	$1,200	$ 840	$ 1,250	$ 930

Vertical Terminal Air Conditioner and Heat Pumps (VTAC/VTHP)

VTAC's sit vertically and provide heating and cooling through ducting without having visible units hanging on the wall. They are packaged units like PTHP's, but larger, and are typically used in hotels in a closet-sized space.

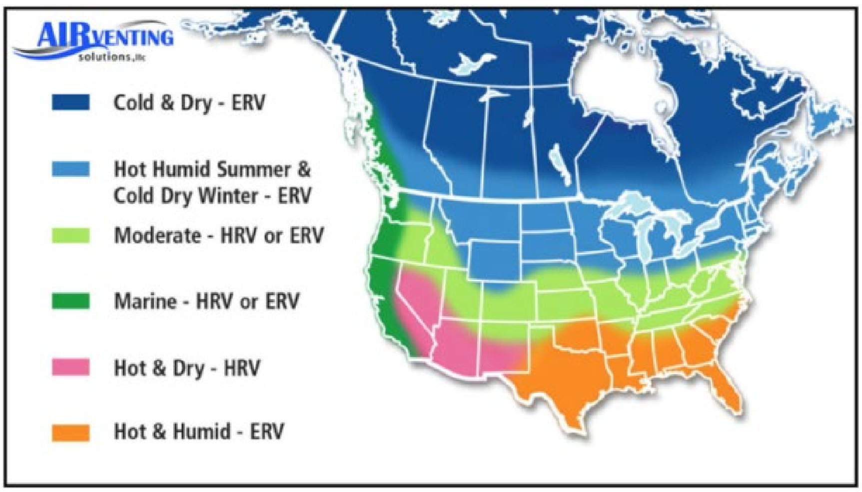
	Ice-Air SPXC(12,18,24) 	**Friedrich** VRP 	**GE** AZ75H(09,12,18)EAC 
Description	Air to Air	Air to Air	Air to Air
Voltage (V)	208	230/208 - 265	208 / 230 or 265
Dimension (in) (HxWxD)	24 x 33 x 23	31 3/4" x 29 7/8" x 77 1/4"	32 x 23 x 23
Ref. Type	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-5 – 95 (cold climate)**	**0 – 70 (cold climate)**	25 Degrees switches to electric resistance heat
Power (W)	884 - 2200	991 - 2570	-
Max Amps (A)	18.8	4.3 - 14.2	-
Heating Cap. (Btu/hr)	7,600 – 25,900	11,400 – 28,500	8,400 – 15,700
Cooling Cap. (Btu/hr)	9,700 – 25,600	12,00 – 33,400	9,500 – 17,500
Heating (COP)	3.5	2.2 - 2.4	2.5 – 3.6
Cooling (COP)	3.8	-	2.9 – 3.1

Heat and Energy Recovery Ventilation (HRV and ERVs)

Heat Recovery Ventilators (HRV) and Energy Recovery Ventilators (ERV) are the same systems but with a different heat exchanger core. The ERV's heat exchanger allows water droplets to be transferred with the heat. The key difference is that an ERV will make your home more humid in winter, and less humid in summer, compared with an HRV.[37] The goal with an HRV is to rid the house of its stale, moist air while transferring the maximum amount of heat into the clean incoming air. This keeps your heat and money inside while filtering contaminated air out. The location of the project will generally determine the need for an HRV or ERV.

The unit operates continuously, sucking air through ducts that are positioned in prime generation locations of moisture and odor, for example, bathrooms and kitchens. As the air flows out to an exterior vent, it passes through a metal box containing a matrix of crimped aluminum plates, full of air channels. At the same time, fresh outdoor air is being sucked into the building, passing through the same box on its way to outlets located in two central locations. The two airstreams never mix, but as they pass each other, heat migrates from the warm outbound stream to the cool inbound, preheating it and reducing load on the heating plant. There is no running cost to this process as all of its operations are done by the laws of physics. In the summer, the system works in reverse, using the house's cooler conditioned air to strip off some of the incoming fresh air's heat, precooling it and reducing load on the air-conditioning system.

Figure 24: Choosing an HRV or ERV system based on location map. [38]



	Fantech VHR70 Fresh Air Appliance 	Fantech FLEX 100H ES Fr. Air Appliance 	BLAUGER ERV EC D(R) 150 	Zehnder ComfoAir Q350 	BLAUGEG KOMFORT EC D5B180(-E) 	BLAUBERG KOMFORT EC SB5506 
Max air flow	57 CFM	104 CFM	181 CFM	206 CFM	220 CFM	441 CFM
Home size	1 to 3-bedroom homes	3 to 4 bedrooms homes	Apartments to small homes	Medium to large homes	Large apartments and homes	Large homes

Ambient / Transported air temp [°F]	-13 to 32 heating	-12 to 32 heating	-13 to 32 heating	-4 to 104	-13 to 140	-13 to 140
Voltage	120	120	120	240	120	120
Max Amps (A)	0.4	1.6	2.5	1.42	0.71	2.3
Sensible Recovery Efficiency (%)	61-72% from -13°F to 32°F	62% - 65% from -12°F to 32°F	77% - 82% from -13°F to 32°F	86.5%	88-98%	88-98%

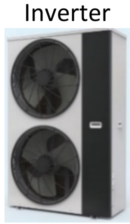
ERV, HRV, and Heat Pump Combinations

The two products below provide filtered ventilation, heat recovery, and supplemental heat pump heating. The heat pump capacity is small, so these are an "all-in-one" solution for smaller single-family homes or apartments and fit into a closest sized space with slim ducting throughout the home.

	CERV-2 	**Minotair** Pentacare V12 
Description	Heat Pump, Ducted Ventilation and HRV	Ducted Heat Pump, HRV, and Ventilation (MERV-15) Combo with 5kW resistance heat
Dim. (in) (HxWxD)	38 x 25.5 x 40	16 x 18 x 40
Ref. Type	-	R410a
Ambient Temp Range (F)	**No low temperature cutoff**	**No Low Temperature cutoff, resistance heater is controlled for efficiency**
Voltage	120V	120V / 240V
Max Amps (A)	12A	6.6A (HP-only), 27A Max
Heating Cap. (Btu/hr)	9,720 (17F) – 11,262 (47F)	5,600 (17F) – 8,700 (47F)
Cooling Cap. (Btu/hr)	7,544 (95F)	11,200 (95F)
Heating (COP)	2.8 – 3.6	2.4 (17F) – 3.0 (47F)
Cooling (COP)	3.2	3.3 (95F)
Price for Unit	-	$6000

Hydronic Heat Pumps (Air-to-Water) (240V)

The air to water (aka hydronic) heat pumps are used in radiant floor heating, domestic hot water and swimming pools and hot tubs in cold climates — note in blue the ambient temperatures in which they can operate.

	Spacepak Split System Inverter	**Arctic** Heat Pump 020A	**Nordic** ATW Series	**Aermec** **ANK** (030,045,050)
Manufacturer and Product Image				

Description	Air to water, heating and cooling, inverter compressor	Hydronic Heating, Domestic Hot Water, Pools and hot tubs	Hydronic heating, fan coils air-conditioning	HVAC and DHW combination
Voltage (V)	240	220-240V	208/230	208/230
Dimension (in) (HxWxD)	55H x 35W x 15D	33 x 18.5 x 45	34 x 34 x 35	50H x 58W x 18D
Ref. Type	R410a	R410a	R410a	R134a
Ambient Temp. Range (H/C) (F)	**-22 – 105 (cold climate)**	**-15 (cold climate)**	**-7 - 120 (cold climate)**	**-4 – 107 (cold climate)**
Power (W)	5,200 – 9,500	2,710 - 3,000	1,190 – 2,500	2,810 – 4,520
Max Amps (A)	32	15	15 - 30	45
Heating Cap. (Btu/hr)	21,000 – 68,000	35,826	4,280 – 22,700	37,670 – 57,598
Cooling Cap. (Btu/hr)	20,400 – 51,600	25,600	17,400	30,120 – 48,240
Heating (COP)	4.23	3.14	1.38 - 4.94	3. 1 – 4.4
Cooling (COP)	4.09	2.5	1.57 - 5.84	-
Price	$7500	$3750	$5000	$5500-$7500

Manufacturer and Product Image	**Stiebel Eltron** WPL (15,20,25) (AS, ACS) 	**Stiebel Eltron** WPL (19A, 23A) 	**Chiltrix** CX34 
Description	Air-to-water heat pump outdoor unit, combined DHW and HVAC	Air-to-water heat pump outdoor unit, combined DHW and HVAC	Air to Water Heat Pump
Voltage (V)	230	230	220
Dimension (in) (HxWxD)	41 x 59 x 23	55 x 49 x 50	38.15 x 43.9 x 16.74
Ref. Type	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-4 (Air) – 140 (Water) (cold climate)**	**-4 (Air) – 149 (Water) (cold climate)**	**-4 – 122 (cold climate)**
Power (W)	1,090 -7,530	2,900	360 - 2,360
Max Amps (A)	7.9 - 30	15	15
Heating Cap. (Btu/hr)	8,525 – 46,500	25,000; 31,000	4,000 - 33,800
Cooling Cap. (Btu/hr)	7,330 – 58,000	-	4,000 – 30,000
Heating (COP)	1.85-5.09	3.0 - 4.12	3.92
Cooling (COP)	2.39-3.76	-	6.75
Price			$4300

Geothermal Heat Pumps (Ground/Water-to-Air/Water) (240V)

Geothermal Heat Pumps rely on the constant temperature in the ground or a large body of water to deliver conditioned air to a home year-round; typically, their coils are buried in the ground and can have various configurations (vertical, horizontal, etc.). In the winter when the temperature above ground is lower than the temperature below the ground, the heat from the ground is transferred into the building for space heating, and vice versa in the summer for cooling. Geothermal heat pumps can provide space heating, space cooling, domestic hot water heating and/or pool heating. For domestic hot water, a desuperheater (which is a small heat exchanger) uses the heat generated form the compressor to heat water for the home. For pool heating, either the heat from the ground can be transferred directly to the pool, or the heat from the ground can be transferred to a compressor (with refrigerant lines) to then heat the water further. Each unit pictured works with ground loops, water loops or ground water loops with optional hot water.

Manufacturer and Product Image	**Nordic** R Series Residential 	**Water Furnace** 7 Series - 700A11 	**York** York Affinity YAF 	**Geostar** Aston Series 	**Bosch** Green Source ES Model 
Voltage (V)	208/230	208/230	208/230	208-230	208-230
Dimension (in) (HxWxD)	66 x 36 x 44	58 x 32 x 26	25x31x58	25x31x58	21x26x54
Ref. Type	R410a	R-410a	R-410A	R_410A	R-410a
Ambient Temp. Range (H/C) (F)	23 – 110	45 – 85 / 45 – 100 (air) 20 – 90 / 30 – 120 (water)	45-100/45-85(air) 30-120/20-90(water)	(45-100) air (30-120) water	50 - 100
Power (W)	1203- 1,764	-	-	-	-
Max - Amps (A)	7.8	32 - 46	-	-	-
Heating Cap. (Btu/hr)	15,200 – 23,000	13,000 – 78,000	14,000-85,000	16400-19500	20,500-80,000
Cooling Cap. (Btu/hr)	20,100 – 26,800	11,000 – 60,000	11,000-66,000	21000-26000	18,000-72000
Heating (COP)	3.7 - 4.9	3.5 - 7.6	4.6-5.9	3.4-5.88	3.6-4.1
Cooling (COP)	5.7 - 9.6	4.7 – 15.6	3.8-5.2	4.8-7.032	41-7.6

Wastewater Heat Recovery Heat Pumps (240V)

SHARC heat pumps harvest heat from human wastewater and other wastewater sources (like laundry room wastewater for one of their projects) and can provide a building with heating and cooling. Wastewater is a great heat resource throughout the year making their heat pumps perform well in the wintertime. Their products can be applied to residential buildings up to campus wide systems, and they have a range of projects in the U.S. and Canada.[39]

Manufacturer and Product Image	**SHARC** Piranha T(5-15) HC 
Voltage (V)	240/460V
Ref. Type	R513a
Description	Wastewater Heat Recovery Heat Pump
Power (W)	5,750 – 11,500
Max - Amps (A)	25 - 50
Heating Cap. (Btu/hr)	60,000 – 180,000
Heating COP	3.8
Cooling Cap. (Btu/hr)	48,000 – 144,000

Electric Cooking

Figure 25: All-Electric Culinary leaders in New York City include many diners, an upscale oyster bar, induction ranges for each customer's Mongolian hot pot and fine Italian dining made with induction woks.

Commercial Electric Kitchens in Mixed Use Buildings

Urban multi-family buildings often have restaurants on the ground floor that benefit from faster, cleaner safer, more efficient all-electric equipment.[40]

- Electric cooking equipment delivers heat three times as effectively than natural gas equipment — heat delivery efficiency is between 60%-90%, compared to natural gas equipment at 25-35% efficient.[41] In addition, ENERGY STAR commercial electric cooking equipment can reduce loads.
- Faster heat delivery is important during rush hours — at a fast-food restaurant an electric fryer produces six more baskets of fries per hour than a gas fryer, directly impacting sales, labor efficiency and profitability.
- Gas inefficiency triples kitchen air conditioning and ventilation loads, and gas combustion pollution (NO_2, Formaldehyde) makes kitchens inherently less healthy for chefs.
- Induction electric cooking offers precise temperature control, while gas burns at 3400°F and then relies upon inefficiencies in heat transfer, or liquids in the pan to cool it. Induction stoves protect chefs from high temperature burns when they bump cookware.

Commercial Electric Ranges

Make/Model	**Bertazzoni** PRO304INMXE 	**Garland** SS686 	**Vulcan** EV36S4FP1HT2 	**AGA Elise** AEL48IN-SS 	**Lang** R36C-APA 	**Garland** SS684 
Price	$3,000	$6,490	$8,440	$8,930	$10,100	$10,400
Amp/Wattage	45.5 / 12.4	78 /19	13kW	50 / 14.9	103.8/21.6	33kW
Volts	240	240	208	240	208-240	208-240
Heating Type	Induction	Radiant	Radiant	Induction	Radiant	Radiant
Temp. Range	NA	150°F - 550°F	200°F-500°F	NA	150°F - 450°F	150°F - 550°F
Burner Diameter	7"(2x)/ 5"/ 8"	6 ½"(x3)/ 8 ½"(x3)	NA	Flattop	24" griddle/8" element(x4)	NA

Commercial Ovens (240V)

Make/Model	**Bakers Pride** BCO-E1	**Vulcan** VC5ED-11D1	**Blodgett** BDO-100-E	**Garland** SUME-100
				
Price	$3,324	$3,715	$3,810	$4,630
Kilowatts	10.5kW	12kW	11kW	10.4kW

Commercial Single Burner Countertop Induction Cooktops (1800 W / 15 Amps / 120V)

Make/Model	**Update** International IC	**Eurodib** C1813	**Waring** WIH200	**ChangBERT**	**Vollrath** 6950020
					
Price	$200	$90	$150	$250	$610
Temp. Range	140°F-460°F	150°F-450°F	Up to 450°F	NA	NA

Electric Induction Woks (240V / 15A)

Make/Model	**Spring** SM-351WCR-8	**Garland** GI-SH	**APW** Wyott IWK	**Vollrath** 6958301	**Garland** GI-SH/WO/IN
					
Price	$1,470	$1,760	$1,950	$2,200	$2,440
kW	3.5	3.5	3	3	5

Electric Fryers (240V)

Make/Model	**Dean** SR114E	**Imperial Range** IFS-40-E	**Frymaster** RE14C-SD	**Anets** AEH14X	**Garland** 36ES11	**Vulcan** CEF40
						
Amp/Wattage	14kW	14kW	39A/14kW	58.3A/14kW	51A/12kW	47A/17kW
Volts	208V	208-240V	208V	240V	240V	208V
Price	$1,650	$1,820	$5,280	$4,140	$5,960	$4,340

Induction Catering and Buffet Equipment (120V)

Make/Model	Garland GI-HO 1500 Induction Warmer 	Spring USA QS7230 Warming table 	Vollrath 7552280 60" Buffet Table 	Bon Chef 50120 Induction Buffet Case 	Bon Chef 50102 96" Buffet Table 
Price	$2,250	$5,700	$6,520	$11,630	$16,120
Amp/ Wattage	NA / 1500W	20A/650W	11.25A / 1350W	50A/NA	30A / 3200W
Voltage	120	120V	120V	220V	110 V

Residential Electric Cooking

The LED "flame" of a Samsung induction stove (at left) is an example of how intuitive it can be to transition to cleaner, faster, and safer all-electric cooking. Natural gas stoves cause unhealthy levels of Nitrous Oxides that would be illegal if it were from a gas power plant. After just 20 minutes of cooking and a sunny window, a kitchen can have actual smog and trigger asthma and lung ailments. Gas cooking appliances are 25-40% efficient, while electric cooking appliances are 70-95% efficient, meaning electric kitchens use 1/3rd as much energy and require only 1/3rd as much cooling. Using electric appliances avoids the construction costs and costs to run extra gas venting equipment. In addition to being more efficient, induction cooking appliances are faster, provide more temperature control and cause less kitchen fires than gas or radiant electric stoves.[42] Below are products that facilitate both retrofits and new construction with high performance cooking equipment. Countertop products do not require any installation retrofits and plug into a standard wall outlet. Drop-in cooktops, on the other hand, are installed into a cut-out of the countertop and hard-wired to a 120V or 240V outlet. Electric cooking comes in a variety of technologies, standard electric, glass top radiant electric, and induction.

Glass Top Radiant Range ($550 or less)

Make/Model	**Amana** AER6303MFS 	**Whirlpool** WFE320M0ES 	**Frigidaire** FFEF3052TS 	**GE Appliances** JBS60DKBB 
Max Power (Watts)	1,800	3,000	100-3,000	3,100
Price	$450	$550	$550	$550
Oven space (cu. ft)	4.8	4.8	4.9	5.3

Glass Top Radiant Range (Greater than $500) (240V using a 40amp circuit)

Make/Model	**Kenmore** 92612 	**Samsung** NE59M4310SS/AA 	**LG** LSSE3026ST 	**Bosch** 800 Series 

Max Power (Watts)	9,600	9,600	13,500	14,800
Price	$700	$700	$1,700	$2,200
Oven Space (cu. ft)	4.9	5.9	6.3	4.6

Slide-In Induction Range (Lowest Cost, 240V, 40 amp)

Make/Model	**Frigidaire** FGIH3047VF 	**LG** LSE4616ST 	**Samsung** Virtual Flame NE58K9560WS 	**GE** Profile PHS930SLSS 	**Frigidaire** Gallery FGIS3065PF 
Price	$1,700	$1,900	$2,400	$2,440	$2,760

Slide-In Induction Range (240V, 40 amp)

Make/Model	**KitchenAid** KSIB900ESS 	**Bosch** HII8056U 	**Café** CHS985SELSS 	**Bertazzoni** PROF304INSROT 	**Fisher & Paykel** OR36SCI6R1 
Price	$2,970	$3,060	$3,420	$4,990	$7499 (50 amp)

Single Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Make/ Model	**Aicok** 	**Avantco** ICBTM-20 Light Duty 	**Avantco** IC1800 Heavy Duty 	**NuWave** PIC Platinum 	**Vollrath** Mirage Cadet 59300 
Price	$40	$50	$120	$200	$270
Temp. Range	140°F - 460°F	140°F - 460°F	140°F - 460°F	100°F-575°F	100°F - 400°F

Single Burner Drop-In Induction (1800W, 120V and using a 15amp circuit)

Make/ Model	**True Induction** TI-1B 	**Avantco** DC1800 	**Adcraft** IND-DR120V 	**Spring** SM-651R 	**Bon Chef** 12083 
Price	$140	$170	$190	$440	$500

Temp. Range	150°F-450°F	140°F-464°F	Up to 464°F	145°F-185°F	150°F-450°F

Double Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Make/ Model	**Eurodib** S2F1 	**NuWave** PIC Double 	**Inducto** 	**Avantco** IC18DB 	**Duxtop** 9620LS 
Price	$200	$200	$150	$150	$190
Temp. Range	150°F -450°F	100°F – 575°F	176°F -460°F	140°F -460°F	140°F -460°F

Multi Burner Induction Stovetops (9600W, 240V using a 40amp circuit)

Make/ Model	**Empava** IDC-36 36" 	**KitchenAid** KCES556 HSS 36" 	**Bosch** NETP068SUC 30" 	**Samsung** NZ36K7880UG 36" 	**Frigidaire** FPIC3677RF 36" 
Price	$900	$1,300	$1,300	$2,300	$2,500

Cooking Energy Use with High Efficiency Cookware

Five types of cookware were compared to find the lowest possible use of cooking energy. Three are insulated: a Crock-Pot slow cooker, a COSORI pressure cooker and an Air Core insulated pot and two non-insulated; a SUNAVO electric hotplate and a Avantco countertop induction range. The standard cooking material used for each type of cookware was chickpeas. One cup of dried chickpeas was soaked for 8 hours, and drained. It was then added to the cookware with 4 cups of room temperature water. The chickpeas were declared fully cooked when the color change was consistent all the way through but not so far as the chickpea would become saturated and loses it structure. For both stovetop methods the pot of water was brought to a boil then left to simmer until the chickpeas cooked to the required texture. Time and energy use in kWh were taken from a P3 P4400 Kill A Watt Electricity Use Monitor.

Insulating your cookware saves energy by dramatically reducing heat loss during cooking. This study concluded that the ideal cookware to reduce energy use are the pressure cooker or slow cooker. Time is always a factor when it comes to the convenience of cooking, so pressure cooker is a great way to limit cooking time while getting similar low energy use as a slow cooker. For a traditional cooking experience, the induction stove top is a great alternative to the electric resistance cooktop. This method saves about 40 minutes in cooking time and uses about 22% less energy.

	Crock-Pot SCR200-R slow cooker 	**COSORI** C3120-PC pressure cooker 	**Avantco** IC1800 countertop induction range 	**SUNAVO** 1500W electric resistance cooktop 	**Air Core** insulated pot w/ SUNAVO electric resistance 
Price	$10	$70	$110	$50	$50
Cooking time (hours)	2.76	0.34	1.21	1.87	0.34

Energy use (kWh)	0.19	0.19	0.64	0.82	0.31
Cost (cents)	3.2¢	3.2¢	10.7¢	13.7¢	5.2¢

**Cost is calculated from the Californian 2019 average of 16.7 cents per kWh.*

Countertop Ovens (120V)

Are you looking to cook a full rotisserie chicken, but live in a tiny home or small electrified apartment? Well look no further, you can live large on a small circuit — countertop kitchen ovens are widely popular and can satisfy your oven cooking needs. The collection below represents the largest countertop ovens on the market that have various functions like convection and air fry technology.

	Luby Large Toaster Oven 	**Aobosi** Convection Toaster Oven 	**Galanz Airfry** Toaster Oven 	**Oster** Countertop Oven 
Oven Size (ft^3)	1.9	1.6	1.5	1.3
Dimensions (DxWxH) (in)	16.1 x 22.0 x 14.4	26.2 x 19 x 18.5	19.3 x 21.8 x 13.0	22.0 x 19.5 x 13.0
Power (W)	1800	1500	1800	1525
Price	$133	$169	$199	$220
Remarks	Mfr. Claims to be able to roast a 20 lb. turkey	Has rotisserie as well as upper and lower heating element settings	"Toast function" French doors	French doors, dials, or digital touch interface.

Electric Laundry Dryers

As our building systems become more efficient, the energy use of appliances becomes more apparent. Laundry loads can sometimes be the largest load, so ensuring that the most efficient equipment is used is important. More surprising may be that the first cause of high use is convenience — households with in-unit laundry run twice as many loads as households with only access to a central laundromat.[43] While washing machines and clothes dryers use about the same amount of motor energy per load, boiling the water out of wet laundry uses 81% of all the energy in an average laundry load in 2010,[44] assuming one is using a standard ~30% efficient gas dryer, rather than a ~250% efficient electric heat pump dryer.

ENERGY STAR, a program led by the US Environmental Protection Agency (EPA), aims to inform consumers and businesses on how to cut down on operating costs by listing and ranking energy efficient products[45]. Until recently, both residential and commercial/coin-operated clothes drying machines were excluded from the list of ENERGY STAR rated appliances because of their consistently high-power demand between all products available on the market. Innovative technologies like moisture sensors, heat pump drying and condensation drying have led to a rise in the availability of residential-grade ENERGY STAR rated dryers.[46] Some examples of residential-grade ENERGY STAR washers and dryers are shown below: standard, combined condensing washer and dryers and heat pump dryers.

Combination Condensing Washer and Dryer

Condensing washer/dryer combine both space and energy efficiency and are ventless — laundry water instead goes down the drain. They are most common in retrofitted apartments in Europe, and run on 120V outlets, using as much energy as a hair dryer on medium and stresses fabrics less. After washing the clothes, the same machine dries the laundry using a condenser.
A laundry cycle, from loading to unloading, takes 2-3 hours.

> "Oh my God, it's a dream come true. Set it and forget it is best thing since sliced bread… we throw our laundry in when we go to bed and wake up to a fresh ready batch. I'll never go back to the disappointment of opening up to wet laundry." – ***Sierra Martinez, a satisfied condensing dryer user***

Combination Condensing Washer & Dryer (120V)

	Magic Chef MCSCWD20W3	**Haier** HLC1700AXW	**Summit** SPWD2201SS	**Deco** DC4400CV	**Whirlpool** WFC8090GX	**LG** WM3998HBA
						
Price	$720	$1,000	$1,000	$1,200	$1,500	$2,000
Energy Use (kWh/year)	85	65	65	96	180	120*
Drum Capacity (cu. ft.)	2.0	2.0	2.0	3.5	2.8	4.5
Volts/Amps	120V/12A	120V/10A	115V/12A	110V/15A	240V/30A	120V/10A

*energy based on older model

Heat Pump Dryers

Heat pump dryers are also ventless but maintain a higher temperature than a condensing dryer and lower than that of electric resistance, and therefore dry clothing at a rate between the two. Note that smaller drum sizes hold less clothes, and consequently take less time to dry. Hybrid heat pump dryers combine resistance elements and heat pump technology to improve overall energy efficiency.

Heat Pump Dryers (240V)

	Samsung DV22N685H	**Blomberg** DHP24400W	**Kenmore** Elite 81783	**Beko** HPD24412W	**Whirlpool** Hybrid WHD560CHW	**Miele** TWI180WP
						
Price	$1,000	$1,100	$1,100	$1,300	$1,250	$1,900
kWh/year	145kWh/year	149kWh/year	-	149kWh/year	460kWh/year	133kWh/year
Drum Capacity (cu. ft.)	4.0	4.1	7.4	4.1	7.4	4.1
Cycle Time (min)	60	46	-	46	70	35

Standard Electric Dryers

ENERGY STAR ranked laundry dryers use a variety of strategies to better eliminate water from clothes, such as fans, humidity sensors and heating technologies. Electric resistance dryers require a vent, while condensing dryers do not. The following products use electric resistance to dry clothes.

Standard Electric Dryers (240V)

	Samsung DV45K76E 	**LG** DLE1501 	**GE** GTD65EB 	**Maytag** MED3500W 	**Whirlpool** WED75HEFW 	**Electrolux** EFME417 
Price	$400	$450	$500	$650	$650	$700
Drum Capacity (cu. ft)	7.4	7.4	7.4	7.4	7.4	8.0
kWh/year	607	607	608	608	608	608

Electric Vehicles

Electric vehicles create no direct air pollution and use just 1/3rd the energy of gas engines. Electric vehicles are the key to reducing the carbon impact of driving, and their battery systems can provide resilience to your home by running critical electric loads when the power goes out — see below discussion of Vehicle to Home charging. The below section provides a list of 2019 model electric vehicles with their specifications, provided by Menlo Spark.[47] For inspiration is also an example of a 1946 pickup truck electrification.

Figure 26: Electric Vehicle Buyer's Guide - August 2020 (Source: Menlo Spark)

ELECTRIC VEHICLE BUYER'S GUIDE*
AUGUST 2020

Manufacturer	BMW	BMW	Chevrolet	Fiat	Hyundai	Hyundai	Jaguar	Kia	Mercedes Benz
Model	2019 i3	2019 i3s	Bolt EV	2019 500e	Ioniq EV	Kona Electric	I-Pace S	e-Niro 4	EQC 400 4Matic
Passengers	4	4	5	4	5	5	5	5	5
Doors	4	4	4	2	4	4	5	4	4
MSRP (from)	$44,450	$47,650	$37,495	$33,460	$34,020	$38,330	$69,500	$38,500	$67,900
Car Body	Hatchback	Hatchback	Hatchback	Hatchback	Hatchback	SUV	SUV	Crossover	SUV
Range (miles)	153	153	259	84	170	258	234	239	220
MPGe City / Highway	124/102	124/102	127/108	121/103	145/121	132/108	80/72	123/102	
MPGe Combined	113 miles	113 miles	118	112 miles	133	120	76	112	
Battery Capacity	42.2 kWh	42.2 kWh	66 kWh	24 kWh	38.3	64 kWh	90 kWh	64 kWh	80 kWh
Horsepower	170	181	200	111	118	201	394	201	
0-60 Speed	7.2 seconds	6.9 seconds	6.9 seconds	8.4 seconds	10.2 seconds	7.6	4.5 seconds	7.5 seconds	4.9 seconds
Top Speed	93 mph	99.4 mph	90.1 mph	85 mph	102.5 mph	103.8 mph	124 mph	103.8 mph	111.8 mph
Charge Time (120 volt)	24-48 hours	24-48 hours	4 miles/hour	24 hours	24 hours	60 hours	2+ days	28 hours	
Charge Time (240 volt)	11-15 hours	9-12 hours	25 miles/hour	4 hours	4 hours 25 min	9 hours 35 min	13 hours	9 hours	10 hours
Quick Charge Option	80% in 41 min	80% in 32 min	to 1000 miles in 30 m	not available	80% in 23 min	80% in 54 min	80% in 45 - 85 minutes	80% in 1 hour	80% in 44 minutes
Max Cargo	39 cu ft	40 cu ft	56.6 cu ft	7 cu ft	23 cu ft	45.8 cu ft	25.3 cu ft	15.93 cu ft	17.66 cu ft
Comments		2020 model available in Europe only		only available in California and Oregon					
Leasing**									
Monthly Rate	$299	$339	$239		$239	$309	$899	$319	
Term (months)	36	36	36		36	36	36	36	
Down Payment	$3,999	$3,999	$1,629		$2,500	$3,999	$5,995	$3,499	

Manufacturer	Mercedes Benz	Mini	Nissan	Nissan	Polestar	Porsche	Rivian	Tesla	Tesla
Model	EQC 400 4Matic	Cooper SE	Leaf S	Leaf S Plus	Posestar 2	Taycan 4S	R1S/R1T	Model S	Model X
Passengers	5	4	5	5	5	4	4	5	5 to 7
Doors	4	2	4	4	5	4	5 or 7	4	4
MSRP (from)	$67,900	$30,750	$29,900	$36,550	$63,000	$106,410		$74,990	$79,990
Car Body	SUV	Hatchback	Hatchback	Hatchback		Sedan	Pick-up	Sedan	SUV
Range (miles)	220	110	149	226	275		300?	402	305
MPGe City / Highway			123/99	118/97				121/112	89/90
MPGe Combined			111	108				117	90
Battery Capacity	80 kWh	32.6 kWh	40 kWh	62 kWh	78 kWh	79.2 kWh	135 kWh	100 kWh	100kWh
Horsepower		181	147	215		214.6 hp		518	502.9+258.8
0-60 Speed	4.9 seconds	6.9 seconds	7.4 seconds			3.8 seconds	3 seconds	3.6 seconds	2.7 seconds
Top Speed	111.8 mph	93.2 mph	89.5 mph	98.8 mph		155.3 mph	124.9 mph	155.3 mph	155.3 mph
Charge Time (120 volt)				27 hours					
Charge Time (240 volt)	10 hours	4.25 hours	8 hours	10 hours	7 hours	7 hours		8.75 hours	5.75 - 8.75 hours
Quick Charge Option	80% in 44 minutes	80% in 39 min	80% in 40 min	80% in 43 min	80% in 31 min	80% in 1.6 hrs	80% in 41 min	80% in 40 min at Supercharger	80% in 50 min at Supercharger
Max Cargo	17.66 cu ft	7.45 cu ft	30 cu ft	30 cu ft	14.27 cu ft	14.37 cu ft	11.65 cu ft	58.1 cu ft	81.21 cu ft
Comments						other models with higher ranges		other models with higher ranges	other models with higher ranges
Leasing**									
Monthly Rate			$163					$921	$1,019
Term (months)			36					36	36
Down Payment			$2,999					$7,500	$7,500

Manufacturer	Tesla	Tesla	Volkswagon		Tesla	Byton	Ford	Kia	Volkswagon	Volvo
Model	Model 3	Model Y	e-Golf	Models coming in 2021 >>	Cybertruck	M Byte	Mustang Mach-E	Soul EV	ID3	XC40 Electric
Passengers	5	5 to 7	5		6	5	5	5	5	5
Doors	4	4	4		4	4	4	4	4	4
MSRP (from)	**$37,990**	**$49,990**			**$39,900**	**$46,595**	**$59,900**	**$37,500**	**29,990 euros**	
Car Body	Sedan	SUV	Hatchback		Pick-up	SUV	**SUV**	Crossover	Hatchback	SUV
Range (miles)	250	230	123		300	270	270	243	205	
MPGe City / Highway	148/132		122/104					127/101		
MPGe Combined	141		113					114		
Battery Capacity	54 kWh		35.8 kWh			95 kwh	75.7 kWh	63 kWh	45 kWh	78 kWh
Horsepower	283		134.1 hp			469.4		201	125	
0-60 Speed	5.3 seconds	5.9 seconds	9.6 seco		6.4 seconds	5.5 seconds	5.5 seconds	7 seconds		4.9 seconds
Top Speed	140 mph	119.9 mph	93.2 mph		110 mph	118.1		105 mph	99.4 mph	111.8 mph
Charge Time (120 volt)								44 hours		
Charge Time (240 volt)	5.75 hours		5 hours					9 hours	6.25 hours	
Quick Charge Option	80% in 30 min at Supercharger		80% in 34-43 min			80% in 38 minutes	80% in 45 minues	80% in 1 hour	80% in 54 min	
Max Cargo	12 cu ft	66 cu ft	12.04 cu ft		100 cu ft	19.42 cu ft	29 cu ft	47.3 cu ft	13.6 cu ft	
Comments	other models with higher ranges	other models with higher ranges					8 models available		offered in Europe in 2020	My only be available in Europe
Leasing**										
Monthly Rate	$371	$499								
Term (months)	36	36								
Down Payment	$4,500	$4,500								

1946 Ford Pickup Truck Gas to Electric Conversion

Story from Franklin Energy

"Commuting by bike in Oakland and inhaling the exhaust of a 1950s Chevy made it clear I could not put our fixer-up dream truck, a classic 1946 Ford pickup, back on the road with a gas engine. The climate friendly solution? Electrify it! After a couple of years of puttering and painting, we have an all-electric antique with a maximum cruising and parading range of 30 miles — enough. The Motor went from 400 lb. flat V-8 engine with 160 lb. of fuel, 560 totals, to a 60 lb. motor with 300 lb. of batteries — 360 lb., 200 lb. lighter than before. Level 1 charging is accessed under gas tank cap and Level 2 at front of truck. The battery design includes handmade battery racks, hood latch, and weatherproofing — a labor of love that can share the road with bicyclists."

Figure 27: Electrified 1946 Fork Pickup truck. [48]

Vehicle to Home and Vehicle to Grid Charging

Vehicle-to-Home Charging was developed in Japan after the 2011 tsunami closed the nation's nuclear power plants. Nissan pioneered the concept of **"Vehicle-to-Home" (V2H)** which uses a charger to isolate a home from the grid and draws on the vehicle's battery power for its electrical needs when grid power is not available. Nissan estimates that its all-electric Leaf can power an average home in Japan for two to four days without solar,[49] and with rooftop solar the system is sufficient for off grid living most of the year. The term **"Vehicle-to-Grid" (V2G)** describes the situation where the car's excess electricity is provided to the grid. The International Energy Agency estimated that in 2030 there will be 130 million electric vehicles on the road, which will contain almost ten times the amount of energy storage needed for a renewably powered grid.[50]

Available Soon in the United States

	Wallbox[51] Quasar 	**Ossiaco**[52] dcbel 	**Nuvve**[53] PowerPort 	**Fermata Energy**[54]
Vehicle-to-Home	X	X		X
Vehicle-to-Grid			X	X
Other Capabilities	• It charges and discharges through a CHAdeMO vehicle connector • Max power of 7.4 kW	• Also operates as a solar inverter and home energy management system	• Max 3-phase power of 99kW • Max single-phase power of 19kW	• Commercial and residential capabilities

Not Available in the United States

A plethora of companies outside the United States have V2H and V2G chargers, demonstrating that these products are tried and tested and ready to come to the United States. Using a car's battery to power your home or to give back to the grid will be an essential service in our all-electric future.

Vehicle to Building (V2B) Chargers			**Vehicle to Grid (V2G) Chargers**			
Honda	**Mitsubishi**	**Nissan**	**Nissan**	**Endesa**	**OVO**	**Princeton Power Systems**
						

Energy Management Systems

Energy Management Systems monitor energy in the home as well as control it. The smart panels and smart circuit splitters shown below can avoid power upgrades by prioritizing different electric loads, like pausing EV charging, allowing the dryer to run, then restarting EV charging. Other products allow scheduling loads, connecting with solar PV, and home battery charging optimization, among many other features. (The Ossiaco product above also has energy management capabilities).

Whole House Panels

Thermolec[55] DCC-9 	**Span**[56] 	**Eaton**[57] Pow-R-Command 	**Koben**[58] GENIUS Smart Panel 
$1025 – 1125	$2,500 including installation costs	TBA	TBA
• Connects EV charger to panel to manage energy loads • real-time reading of total power use of electrical panel; if panel exceeds 80% rated load, then temporarily de-energizes the vehicle charger. Reconnects automatically when other loads allow	• Replaces traditional electrical panel in the home • Can monitor and control electrical use at the circuit level • Puts control into the hands of the homeowner with intuitive smartphone app • Plug in play solution for rooftop solar, battery storage and EV charging	• Control lighting and plug loads with time and space occupancy schedules to maximize energy savings • 15 A, 20 A and 30 A configurations in single- and two-pole models suitable for voltage systems up to 480V • Can add expansion panels up to 168 controllable circuit breakers	• Replaces old electrical panel and allows home to become "Smart Grid" ready • integrates EV Charging, Solar, Battery Storage, Generator and your trusted energy provider whether you are planning for the new energy era or have already installed your new energy technology.

Subpanels

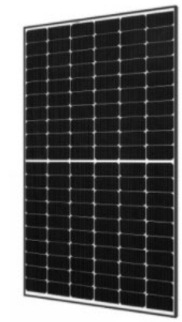
Eaton[59] Energy Management Circuit Breaker (EMCB) 	• Programmable breakers to prioritize loads in restoration scenarios, control shedding of lighting and plug loads • Remote cycling of HVAC, WH, to offset energy demands and save money • Can connect with solar monitoring, home networks and demand response • In the future could simplify EV charging	**Lumin**[60] Smart Panel 	• Real time balancing of battery use and charging • Manages renewable generation, energy use and storage • Dynamic switching of loads based on time of use rates • Off-grid mode sheds non-critical loads and islands • Can pair with batteries to create an integrated energy management system, removes requirement of a subpanel or protected loads panel • Programmable schedules to automatically control loads • Max size: (x6) 60A, (x6) 30A

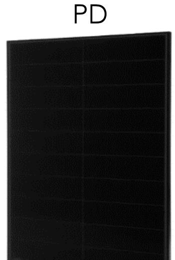
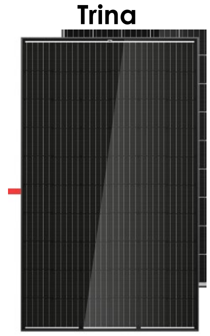
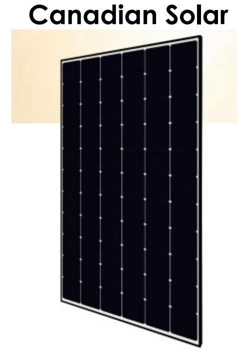
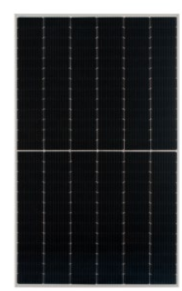
Smart Circuit Splitters (EV Charging and Appliances)

Thermolec[61] DCC-9 	**Neo Charge**[62] Smart Splitter 	**BSA Electronics**[63] Dryer Buddy 	**SimpleSwitch**[64] 240V Circuit Switch 	**SimpleSwitch**[65] 120V / EV Circuit Switch 
\$1,050 (DCC-9), \$945 (DCC-10)	\$450 (smart splitter and appliances) \$500 (dual car splitter, on-the-go)	\$200 – 365 (several outlet versions)	\$550 (240V)	\$550 (120V) / \$650 (EV)
• Connects EV charger to panel to manage energy loads • Real-time reading of total power use of electrical panel; if panel exceeds 80% rated load, then temporarily de-energizes the vehicle charger. Reconnects automatically when other loads allow • DCC-10 uses one double pole breaker slot	• Level 2 charging without rewiring or panel upgrade • Pauses EV charging for other large loads then resumes charging • "Dual car" option – charge two EVS at half power, or fully charge one then the other • "Dual appliance" option can allow water heaters and dryers to share a circuit	• Plugs into a 30A circuit (common dryer plug) and allows for vehicle charging while dryer is not in use. • It has a digital display that shows the draw of each load. • Versions available with different outlet types depending on what appliance you have	• One load is the "primary" load and the other is the "auxiliary" – if the primary load comes on, the auxiliary load will shut off. • 240V version is UL-listed for use with breakers up to 50A • No permits needed for install – save on costs • Can be configured to split the circuit	• Circuit switching is the same process as the 240V version • EV version is EVSE Level 2 and comes with built-in 24-amp or 32-amp charger • Buy one product to tee-off your new EV circuit and charge your new EV • Useful for short-load/cyclic-load sharing such as electric cooking with overnight EV charging • 120V version available for purchase empowers low-power circuit sharing in trailer homes and apartments with limited panel space
Hardwired, can use your favorite rated NEMA outlet	NEMA 10-30, 14-30, 14-50 (10-50 for portable)	NEMA 10-30 to 10-30, 10-30 to 14-50, 14-30 to 14-30	NEMA rated plugs standard Optionally hardwired, can use your favorite rated NEMA outlet	NEMA rated plugs standard Optionally hardwired, can use your favorite rated NEMA outlet
Shuts off EV load when panel reaches 80% load	Turns off one appliance when the other comes on	Shares power between appliance and EV (both powered)	Turns off one appliance when the other comes on	Turns off one appliance when the other comes on

Solar Photovoltaic Panels

The cost of installing solar in a home depends on the amount of electricity a homeowner wants to generate. A bigger system can be more costly because it requires more equipment or labor, and design time if the roof is complex. Over the last 10 years residential photovoltaic systems have dropped more than 60% for a commonly used 6 kW system from $50,000 to about $20,000 or less. Currently, there is a 30% tax credit from the Federal Government on installing solar in homes which is lowering to 22% in the year 2021 and by the year 2022 there will only be a 10% tax credit for commercial buildings. Some other factors that may affect the price of solar are the state you are in, how much energy you use, a roofs' sunlight exposure, and manufacturer of the panel. The break down cost of solar photovoltaic is about 47% of cost is for solar equipment, 35% of cost is for installation & permits, and 18% of cost is for operation and improvement. Below is some of the leading manufacturers of solar panels with their associated cost.

	SunPower Maxeon® Gen5 	**Q Cells** Q.Peak DUO ML-G9 	**REC** Alpha 	**LG** Neon 2 	**Winaico** WSP-340MX 
Type	Monocrystalline	Monocrystalline	Monocrystalline	Monocrystalline	Monocrystalline
Power Output (W)	400	390	370	345	340
Efficiency	22.3%	20.8%	21.2%	20.1%	19.4%
Size (in) (LxWxD)	Contact SunPower	72.4 x 40.6 x 1.3	67.8 x 40 x 1.2	66.9 x 40 x 1.6	67.2 x 40.5 x 1.4
Price ($)		$240	$360	$310	Contact Winaico

	Solaria PowerXT-370R-PD 	**Panasonic** HIT 	**Trina** 	**Canadian Solar** 	**Jinko Solar** 
Type	Monocrystalline	Monocrystalline	Monocrystalline	monocrystalline	monocrystalline
Power Output (W)	370	340	275-315	237-255	455
Efficiency	19.4%	20.3%	19.2%	19.9%	20.6%
Size (in) (LxWxD)	63.8 x 43.9 x 1.6	62.6 x 41.5 x 1.6	65.0x 39.1x 1.38	81.8x39.1x1.38	85.91x40.51x1.59
Price ($)	$360	$340	contact	contact	Contact

Electric Battery Storage

Battery storage provides resiliency during disasters and restoration efforts, can be sold to utilities as a resource for their grid management, or allow you to go off-grid in more rural regions. Solar electric panels, with rare examples of residential wind turbines and micro hydro dams, are paired with batteries and often an energy management system to make it easy for occupants to live within their energy budget. An innovation discussed above, vehicle to home charging, gives the possibility of delivering more power to a home with an electric car, a needed alternative to the too-common practice of using gas generators to meet loads during the least sunny parts of a winter. Owners and builders can include the full solar plus energy storage when they build or remodel, or pre-wire for the capability to add these systems later.

Battery Systems

Battery systems have dropped 87% in price over the last decade, from $1100/kWh in 2010 to $156/kWh in 2019, helping drive the rapid international growth in affordable electric vehicles and home batteries.[66] Home batteries can be modest and scaled to a reduced set of power needs during restoration, or large and able to take your home "off-grid" altogether. Home batteries are now so common that you can pick up a Yeti battery power pack as an alternative to a home generator at Home Depot.[67] Sunshine is roughly 1/5th as strong on Winter Solstice as Summer Solstice, which makes powering a home off grid with just solar panels a challenge without significant efficiency efforts, resorting to fossil fuel generators, or getting power from a grid-charged electric car (see below Vehicle to Home section). Home batteries are made with a variety of chemicals and minerals, but leading products currently all incorporate Lithium, which is highly reactive, lightweight, and relatively common, found on every continent in rocks of volcanic origin and mined heavily in Chile, Australia, and China. Some manufacturers such as Sonnen include inverters Wi-Fi integration and in the cabinet as a standalone unit.

	DC Batteries			AC Batteries			
DC Battery	**Blue Planet** Energy	**LG** RESU 10H	**SimpliPhi** Power 2.4	**Tesla** Powerwall	**Panasonic** EVDC-105	**Sonnen** Eco	**Sonnen** EcoLinx
							
Capacity (kWh)	8, 12, 16	9.3	2.4	13.5 (combinations up to 135)	5.7, 11.4, 17.1	5 – 20 (2.5 kWh steps)	10, 12, 14, 16, 18, 20
Round Trip Eff.	98%	94.5%	98.0%	98%	89%	90%	86%
Chemistry	Lithium Iron Phosphate	Lithium-ion	Lithium Iron Phosphate	Lithium Nickel Manganese Cobalt Oxide	Lithium-ion	Lithium Iron Phosphate	Lithium Iron Phosphate
Price	-	$5,520	-	$7,600 (+ $2,500 install)	$12,700, $15,300 $18,500	$9,000 (5kwh)	-

Electric Landscaping

Powerful electric landscaping equipment uses lightweight batteries and efficient motors that are half as loud as gas equivalents, produce no local air pollution, and are easier to maintain. Modern batteries now offer comparable length of operating time to gas tanks, and batteries are safer to store than gasoline, oil, and rags.


	Blower	**Chain Saw**	**Pole Pruner**	**Trimmer**	**Hedge Trimmer**	
STIHL[68]	BGA 100 ($350) 	MSA 160 C-BQ ($350) 	HTA 85 ($490) 	FSA 130 R ($400) 	HAS 94 R ($500) 	RMA 510 ($520) 
Husqvarna[69]	550iBTX ($500) 	T536Li XP ($400) 	536LiPT5 ($500) 	536LiLX **($300)** 	536LiHD60X ($430) 	LE221R ($430) 
RYOBI[70]	RY40440 ($270) 	P549 ($200) 	RY40561 ($200) 	RY40250 ($160) 	RY40610A ($150) 	RY48ZTR100 ($4100) 

*Prices will vary – visit retailers for the most current cost information.

Electric Snowblowers

There is a wide range of electric snowblowers on the market ranging in cost from a few hundred up to about $800 USD. The are many benefits of electric vs. gas snowblowers: they do not require oil changes, filter changes, new spark plugs, or any gasoline; storage and use is safer; they are significantly quieter; produce less emission; and can be cordless with battery power.

	EGO SNT2102 	**Snow Joe** iON18SB 	**PowerSmart** DB2401 	**Earthwise** SN74018 	**Toro** 38381 	**Snow Joe** Ultra SJ620 
Terrain	Paved & Gravel	Flat/Paved	Flat/Paved	Flat/Paved	Flat/pave d	Flat/pave d
Snow handling	Heavy wet to fluffy light	Heavy wet to fluffy light	Moderate dry to fluffy light	Heavy wet to fluffy light	Fluffy light	Fluffy light
Lbs. of snow/min	1500	500	700	500	700	650
Battery requirements	(2) 56-Volt 5.0Ah Lithium- Ion	40-Volt 4.0-Ah Lithium-Ion	40-Volt 4.0 Ah Lithium-Ion	40-Volt 4.0 Ah Lithium-Ion	-	-
Run time	15 minutes	65 minutes	25 minuets	30 minuets	-	-
Throwing distance	35ft	20ft	30ft	30ft	30ft	20ft
Clearance in. (WxD)	21 x 10	18 x 8	18 x 11	18 x 12	18 x 8	18 x 10
Weight	70 lbs.	32 lbs.	18.5 lbs.	35 lbs.	25 lbs.	31.5 lbs.
Price	$600*	$300*	$270*	$250*	$280	$150

*batteries and charger included

Electric Snowmobiles

Gas-powered snowmobiles have little to no standards and many have two stroke engines causing them to be sometimes as much as 50 times more polluting than the average car.[1] Less emissions and pollution is an obvious plus, but financially these machines also have the huge advantage of no improvement costs. There is no fuel, no oil, no transmission, and no drive belts so the cost of operation is much lower and that means more time can be spent out riding rather than doing costly fixes back at home. These snowmobiles are compatible with and can charge anywhere with automotive standard equipment. The average charging time with the AC 240V L2 charger is 2 hours but now there is also a DC fast charger which can bring the battery up to 80% in just 20 minutes.[71]

	Taiga Motors Ekko TS3 	**Taiga Motors** Atlas 	**Taiga Motors** Nomad 

Range (km)	131	140	134
Engine Package	180hp	180hp	120hp
Battery	27 kWh	27 kWh	27 kWh
Weight (ride ready)	66kg / 586lbs	271kg / 597lbs	275kg / 607lbs

Electric Fireplaces

Figure 28: A Dimplex Opti-Myst cassette within a commercial space.[72]

Swirling, fire-like mist lit with LEDs and a campfire's worth of heat: these are electric fireplaces. They are less expensive than gas stoves, safer, cleaner, and plug into a normal 120V wall outlet. They provide heat in a more efficient and smokeless way – a 3,000-Watt electric fireplace can warm spaces up to 800 feet and look great doing it. From convincing to dramatic, electric fireplaces are ready to match the tastes of any owner. Outdoor electric space heaters are similarly versatile and ready to replace headache-inducing propane burners.

What is a water vapor fireplace?

Ultra-fine water vapor, LED lights, and different air pressures allow realism within the mist flames to replace actual fire to reduce emissions in a building. A transducer helps convert pressure into an electrical signal that forms ultrasounds that vibrates water and turns it into ultra-fine water vapor and LED lights illuminate a life-like flame effect. The depth of the frame can be customized as well by adjusting the opening where the water vapor comes out. Opti-Myst has many different styles of LED water vapor fireplaces to provide a more comfortable aesthetic environment in residential, commercial, and high-rise buildings. A Firewater has also released a set of fireplaces that consist of water vapor flames with multicolored options to provide occupant comfort within public and private spaces.

Why buy an LED fireplace?

These fireplaces do not only feel like a real fireplace, but they are the safest and cleanest electric technologies to put within a home or office. Unlike real fireplaces, they are not emitting CO_2 into a space and can be controlled for optimal comfort and aesthetics.

	Dimplex Opti-Myst (CDFI 500-PRO) 	**Dimplex Opti-Myst** (CDFI 1000-PRO) 	**AFIREWATER** 	**Dimplex Opti-Myst** (GBF 1000-PRO) 	**Dimplex Opti-Myst** (GBF 1500-PRO) 
Price ($)	$1,430	$2,640	$3,460	$3,630	$5,640
Power (Watt)	230	460	60-180	1400	1460

Amps	1.91	3.8	Not Available	11.67	12.17
Voltage (V)	120	120	120	120	120
Heating (BTU)	785	Not Available	Not Available	4981	4981

Electric Outdoor Heaters

Keeping warm outside does not need to come from odorous and polluting propane outdoor heaters, there are many electric equivalents that range from wall mounted high power 240V to free standing 120V options for your outdoor heating needs.

Wall Mounted

	Bronic	**Sunheat**	**Heatstrip**
			
Power (W)	2300	4500	6000
Voltage (V)	240	240	240
Price	$985	$450	$800
	Infratrech	**RADtec**	**Heatstrip**
			
Power (W)	6000	1500	1500
Voltage (V)	240	120	120
Price	$800	$150	$200

Free Standing

	Ener-G+	**Fire sense**	**Aura**
			
Power (W)	1400	1500	1500
Voltage (V)	120	120	120
Price	$300	$300	$400

Electric Barbeques

Electric BBQ grills heat up much more quickly than charcoal or gas grills and distribute heat more evenly over the entire grill area. With no charcoal fumes and no propane gas burning, they are safer and can be used indoors in inclement weather. Electric grills are cheaper to operate, clean up easier, need little improvement and can also be used in high rise buildings where typical combustion grills are not allowed due to fire code restrictions.

	Electri Chef The Safire 115V	**Electri Chef** Emerald 24"	**Electri Chef** Ruby 32" Built-in	**Kenyon** B70590	**Kenyon** B70060
					
Cooking Surface (sq. in.)	224	336	448	115	115
Price	$700	$3,600	$3,500	$1200	$650
Voltage	115V	220V	220V	120V	120V

	Weber 55020001	**Char-Broil** 804142	**Kuma** Profile 150	**Americana** 9359U8.181	**Maverick** E-50S
					
Cooking Surface (sq. in.)	280	240	145	200	173
Price	$320	$200	$220	$245	$180
Voltage	120V	120V	110	120V	120V

	Fire Magic E250S-1Z1E-P6	**Char-Broil** Patio Bistro 240	**Weber** Q 2400	**Meco** Easy Street	**Kenyon** Floridian
					
Cooking Surface (sq. in.)	240	240	280	200	240
Price	$1400	$190	$246	$248	$710

Type	Patio Post	Mobile	Mobile	Mobile	Built-in
Voltage/ Amp	120V / 20A	120V / 15A	120V / 13A	120V / 12.5A	240V / 5.5A
Heat Output	1800W	1750W	1560W	1500W	1300W

Electrically Heated Swimming Pools and Hot Tubs

Utilizing a heat pump can be an efficient way to address the energy demands of heating a pool. To size a heat pump pool heater, assume the heat pump must produce 4 to 6 BTUs/hour for each gallon of heated pool water, with higher productivity needed when the incoming water is colder in the winter. In addition, solar thermal can be an efficient way to heat pools or supplement pool heating.

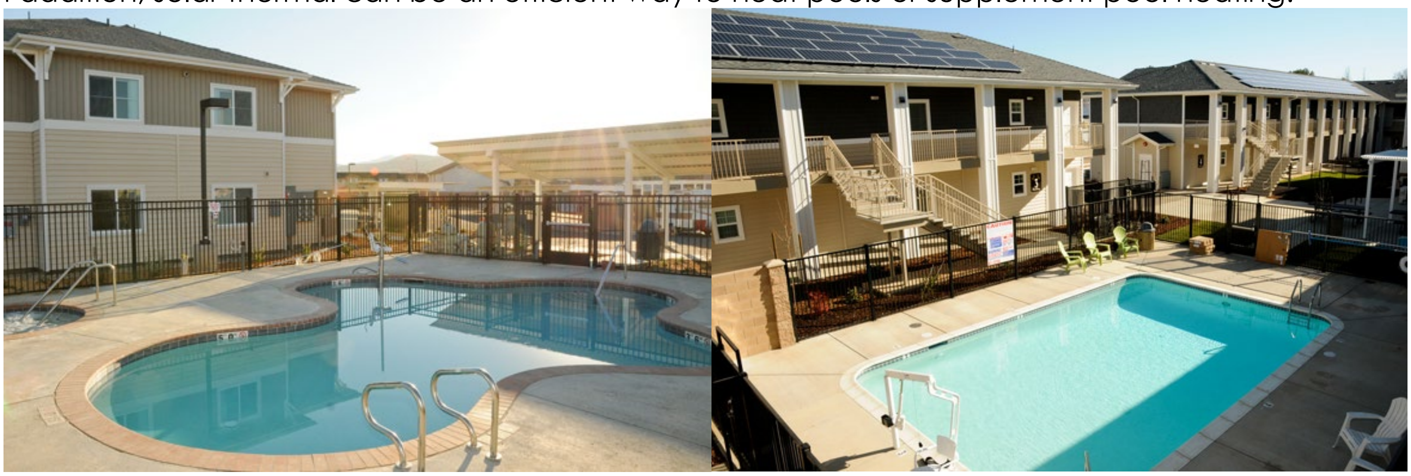


Figure 29: Pacific Companies Zero Net Energy apartment complexes built in 2014 use heat pumps for the hot tub and swimming pools (left King Station Apartments, King City, CA and right Belle Vista Senior Apartments, Lakeport, CA.)

Listed briefly below are heat pumps specifically designed for pools and cost $2400-$4200 for 90,000 BTUs/hr. to 140,000 BTUs/hr. of heating, about 1/10th the price of a similar-sized solar thermal pool heater. Heat pumps significantly reduce construction costs compared to solar thermal while providing the same ~80% offset of energy use by using ambient heat in the air, while working all 12 months of a year, compared to five to eight months of renewable pool heating with solar thermal panels.

	Hayward HeatPro Electric Heater	**Pentair** UltraTemp 110 Heat Pump	**PHNIX**	**AquaCal HeatWave** SuperQuiet SQ120R	**AquaCal** Great Big Bopper
					
Price	$3,000	$3,270	price unavailable	$4,200	Contact AquaCal
Heating Capacity (BTU/hr.)	140,000	108,000	117,000	110,000	527,000
Heating COP	6.0	5.8	6.2	5.5	6.6
Temp. Range	50-104°F	45-104°F	50-110°F	55-100°F	-

Electric Sauna Heaters

The following section offers alternatives to gas powered saunas: electric resistance and infrared. Electric resistance saunas offer an experience just like traditional saunas – electric resistance coils warm up rocks so that water can be poured over them to create steam. Infrared saunas are different from traditional steam saunas – they use low intensity infrared lights to increase body temperature, which is better for the lifetime of the wood rooms and creates an enjoyable experience comparable to steam.

Electric Resistance, heater unit only (240V)

Model	**Finlandia** FLB30-ESH	**Finlandia** FLB80-ESH	**Polar** HNVR 45SC	**Harvia** HPC-HTR61	**Harvia** HNC-HTR105
Picture					
Capacity (kW)	3.0	8.0	4.5	6.8	10.5
Price	$630	$780	$910	$1,070	$2,040

Infrared, Full Room (120V)

Model	**JNH Lifestyles** MG217HB	**Radiant Saunas** BSA2409	**Cedarbrook** CBLGTMD1
Picture			
Price	$1,100	$1,400	$2,040

1 Consumers Energy. (June, 2021). “2021 Clean Energy Plan.” https://www.consumersenergy.com/-/media/CE/Documents/company/IRP-2021.ashx

2 Engelberg, Jeremy and Brassell, Evan. (2019). “Differences in Fuel Usage in the United States Housing Stock: American Housing Survey Report.” U.S. Census Bureau. https://www.census.gov/content/dam/Census/library/publications/2019/demo/h150-19.pdf

3 Statista. (2020). “Unit shipments of electric/gas cooking appliances in the U.S. from 2007 to 2017.” https://www.statista.com/statistics/295477/unit-shipments-of-electric-gas-cooking-appliances/

4 Statista. (2020). “Gas dryer unit shipments in the United States from 2005 to 2017.” https://www.statista.com/statistics/322357/gas-dryers-shipments-united-states/

5 Golden, R. and Bottorff, C. (2020). New Analysis: Heat Pumps Slow Climate Change in Every Corner of the Country. Accessed: https://www.sierraclub.org/articles/2020/04/new-analysis-heat-pumps-slow-climate-change-every-corner-country?

6 Consumers Energy (2019) Clean Energy Plan https://www.consumersenergy.com/-/media/CE/Documents/sustainability/integrated-resource-plan-summary.ashx?la=en&hash=9F602E19FE385367FA25C66B6779532142CBD374

7 Architecture 2030. (2020). Why the Building Sector? <https://architecture2030.org/buildings_problem_why/>

8 Environmental Defense Fund. (2020). Methane, The Other Important Greenhouse Gas. *EDF calculation based on IPCC AR5 WGI Chapter 8.” <www.edf.org/climate/methane-other-important-greenhouse-gas> Note that other sources like livestock (e.g. cows) contribute to methane emissions also.

9 Federal Energy Information Administration. (2019). “One in four U.S. homes is all-electric.” https://www.eia.gov/todayinenergy/detail.php?id=39293

10

11 Stone Energy Associates, Accounting for Cost of Gas Infrastructure, CEC Docket 17-BTSD-01 (May 4, 2017), https://efiling.energy.ca.gov/GetDocument.aspx?tn=217420&DocumentContentId=26959

12 Home Advisor. (2020). “2020 Cost to Install a Dryer Vent.” https://www.homeadvisor.com/cost/heating-and-cooling/dryer-vent-installation/#:~:text=Most%20homeowners%20spend%20between%20%2480,material%20quality%2C%20and%20installation%20difficulty.

13 Konkle, D. (2014). A Guidebook for Community Solar Programs in Michigan Communities. Great Lakes Renewable Energy Association. Pure Michigan Energy Office. <https://www.michigan.gov/documents/mdcd/Michigan_Community_Solar_Guidebook_437888_7.pdf>

14Engineer’s Energy Consumption Model Form. Michigan State Housing Development Authority. 10/09/2018. https://www.michigan.gov/documents/mshda/mshda_crh_ilu_24_engineers_energy_consumption_model_form_635510_7.pdf

15 Consumers Energy. (2020). Outage Center. https://www.consumersenergy.com/outages/outage-center

16 Ayyagari, S., Gartman, M., and Corvidae, J. (2020). Surviving the Next Polar Vortex - Efficient Building Envelope Make Houses Safer for Longer in Extreme Cold Weather Events. Accessed: https://rmi.org/surviving-the-next-polar-vortex/

17 Eaton. (2018). Power Outage Annual Report Blackout Tracker United States Annual Report 2018. Accessed online at: https://switchon.eaton.com/plug/blackout-tracker

18 EVsmartBlog. (2019). Experiences of victims who survived the Chiba power outage of 2019 with electric cars and V2H. <https://blog.evsmart.net/electric-vehicles/report-from-2019-chiba-power-outage/?>

19 U.S. Energy Information Administration. (2019). Michigan State Energy Profile. https://www.eia.gov/state/print.php?sid=MI

20 Midwest Energy Efficiency Alliance. (2017). Midwest Multifamily Market Characterization, Building Attributes and Occupant Demographics. https://www.mwalliance.org/sites/default/files/meea-research/meea_2017_midwest-multifamily-market-characterization_v1.0-final_web.pdf

21 Passive House Principles (2020). https://www.phius.org/what-is-passive-building/passive-house-principles

22 Assa, Emmanual. (2017). Saving Green: Environment Sustainability and Affordability in Rental Developments. http://bay.stanford.edu/blog/2017/4/19/saving-green-environmental-sustainability-and-affordability-in-rental-developments

23 Saffron, I. (2020). The apartment building of the future is here, and it looks like a giant battery. The Philadelphia Inquirer. < https://www.inquirer.com/real-estate/inga-saffron/green-architecture-climate-change-design-onion-flats-tim-mcdonald-front-street-el-inga-saffron-20200305.html>

24 R-951 Residence. Accessed: http://www.r-951.com/

25 NYSERDA. (2020). Further Inc.’s R-951 Residence – Passive House/Net Zero Multifamily Building. https://www.nyserda.ny.gov/All-Programs/Programs/Low-Rise-Residential/Featured-Projects/Further-R-951

26 Refrigeration Kings. (2019). “Protect Your Heat Pump From the Harsh Atlantic Weather” <https://www.kingsrefrigeration.com/residential/heat-pump-accessories>

27 Sanden. (n.d.) Heat Pump Water Heater. <https://www.sandenwaterheater.com/sanden/assets/File/SANDEN_CO2WaterHeaterG3_3_17.pdf>

28 Transcom. (2020). <https://www.transomcorporation.com/products/hatch-air-source-heat-pump/>

29 C&I Case Studies in Beneficial Electrification (2018): Agribusiness: Dairy Water Heating. Retrieved from: www.cooperative.com/programs-services/bts/documents/techsurveillance/ts-beneficial-electrification-dairy-water-heating-april-2018.pdf

30 Several Presentation Links from Shawn Oram of Ecotrope are provided: Heat Pump Are Not Boilers, Shawn Oram Presentation ZNE Retreat July 2018, RCC Pilot Project: Multifamily Heat Pump Water Heaters in Below Grade Parking Garages in the Pacific Northwest, Central Heat Pump Water Heating with 3 Case Studies

31 Renew. Heat pump hot water systems. <https://renew.org.au/resources/how-we-can-help/efficient-electric-homes/how-we-can-help-heat-pump-hot-water-systems/>

32 John Miles. SANCO2 performance curves at cold temperatures [email correspondence]. Message to: Sean Armstrong. 2020 Oct 29.

33 SANCO2 Water Heater. (2020). Twitter, <https://twitter.com/sandenco2hpwh?lang=en>

34 SANCO2 Water Heater. (2020). Twitter, <https://twitter.com/sandenco2hpwh?lang=en>

35 Beuerlein, K. Is Ductless Heating and Cooling Right for You? HGTV. <https://www.hgtv.com/remodel/mechanical-systems/is-ductless-heating-and-cooling-right-for-you>

36 LG (2019). Residential/Light Commercial Systems Counter Quick Reference Guide. < https://www.victordist.com/content/PI_Home_Comfort_Solutions_Reference.pdf>

37 https://www.thisoldhouse.com/milton-house/21015136/the-case-for-installing-a-heat-recovery-ventilator

38 The difference between an HRV and an ERV - AVS - the Best Choice. (2020). < http://www.airventingsolutions.com/how-to-choose-between-hrv-erv-home-ventilation-systems-usa-canada>

39 Sharc Energy. (2020). <https://www.sharcenergy.com/sharc_products/>

40 Kostuch Media Ltd. (2017). Why Induction Cooking is the Hottest Trend to Hit Restaurant Kitchens. Food Service and Hospitality. <https://www.foodserviceandhospitality.com/why-induction-cooking-is-the-hottest-trend-to-hit-restaurant-kitchens/>

41 Source: Andre Saldivar, Foodservice Technology Center, Southern California Edison

42 See the Induction Cooking Fact Sheet by Tom Lent: <https://docs.google.com/document/d/1qiGX6-tFdawfA6Nqp8SYifRbtucX9RzqAdjZ_5NdwBE/edit>

43 Baylon et. al. (2013). “Residential Building Stock Assessment: Multifamily Characteristics and Energy Use.” Ecotope, Inc. for NEEA.

44 Korn & Dimetrosky. (2010). “Do the Savings Come Out in the Wash? A Large-Scale Study of In-Situ Residential Laundry Systems.” The Cadmus Group. ACEEE Summer Study on Energy Efficiency in Buildings

45 U.S. Department of Energy. (2017). “Saving Energy and Money with Appliance and Equipment Standards in the United States” <https://www.energy.gov/sites/prod/files/2017/01/f34/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet-011917_0.pdf>

46 Janeway, K. (2014). “Finally, the lowly dryer can reach for ENERGY STAR” <https://www.consumerreports.org/cro/news/2014/05/finally-the-humble-dryer-can-reach-for-energy-star/index.htm>

47 Electric vehicle tables courtesy of Menlo Spark. Go to www.menlospark.org to learn more.

48 Truck restoration story and photos courtesy of Amy Dryden of Franklin Energy.

49 Gerdes, J. (2019). Will Your EV Keep the Lights On When the Grid Goes Down? Green Tech Media. <https://www.greentechmedia.com/articles/read/will-your-ev-keep-the-lights-on-when-the-grid-goes-down>

50 McMahon, J. (2019). All The Energy Storage The Grid Needs Will Soon Be Under Our Noses. Forbes. <https://www.forbes.com/sites/jeffmcmahon/2019/11/12/all-the-grid-batteries-we-need-and-more-will-soon-be-under-our-noses/#696c61f136e3>

51 Wallbox. (2020). https://wallbox.com/en_us/
52 Ossiaco. (2020) Dcbel. Your Energy Without Compromise. <https://dcbel.ossiaco.com/>
53 Nuvve. (2020). https://nuvve.com/2019/05/01/nuvve-powerport/
54 Fermenta Energy. (2020). https://www.fermataenergy.com/homeowners
55 DCC. (2018). DCC-9 <https://dcc.technology/dcc-9/>
56 Span. (2019). Flexible energy for the modern home <https://www.span.io/>
57 Eaton. (2017). Eaton Pow-R-Command intelligent panelboard. <https://www.eaton.com/ecm/groups/public/@pub/@electrical/documents/content/pa144001en.pdf>
58 Koben. (2020). Energy Management. The GENIUS Smart Panel. <https://kobensystems.com/energy-management/>
59 Eaton. (2019). Energy management circuit breaker <https://www.eaton.com/us/en-us/markets/innovation-stories/energy-management-circuit-breaker.html>
60 Lumin. (2019). Lumin energy management platform <https://www.luminsmart.com/platform>
61 DCC. (2018). DCC-9 <https://dcc.technology/dcc-9/>
62 NeoCharge. (2019). NeoCharge Smart Splitter <https://www.getneocharge.com/>
63 BSA Electronics. (2019). Dryer Buddy <https://www.bsaelectronics.com/collections/dryer-buddys>
64 SimpleSwitch. (2020). https://simpleswitch.io/products/simple-switch
65 SimpleSwitch. (2020). https://simpleswitch.io/collections/all
66 Bandyk, Matthew. “Battery prices fall nearly 50% in 3 years, spurring more electrification: BNEF.” Utility Dive. Dec. 3, 2019. <https://www.utilitydive.com/news/battery-prices-fall-nearly-50-in-3-years-spurring-more-electrification-b/568363/>
67 Goal Zero. Discover Power Station. <https://www.goalzero.com/product-features/portable-power-stations/>
68 STIHL. (2019) “AP Series” <https://www.stihlusa.com/products/battery-products/ap-series/>
69 Husqvarna. (2019). “Battery Series” https://www.husqvarna.com/us/products/battery/
70 RYOBI. (2019). “Lawn and Garden” https://www.ryobitools.com/outdoor
71 Taiga Electric. (2020). Snowmobile - 100% electric high torque sleds. Retrieved 29 October 2020, from https://taigamotors.ca/snowmobiles/
72 Modern Blaze (2020). Commercial electric fireplace. <https://www.google.com/maps/uv?pb=!1s0x88137ddbda180241%3A0xd2a0ba797ab5122b!3m1!7e115!>