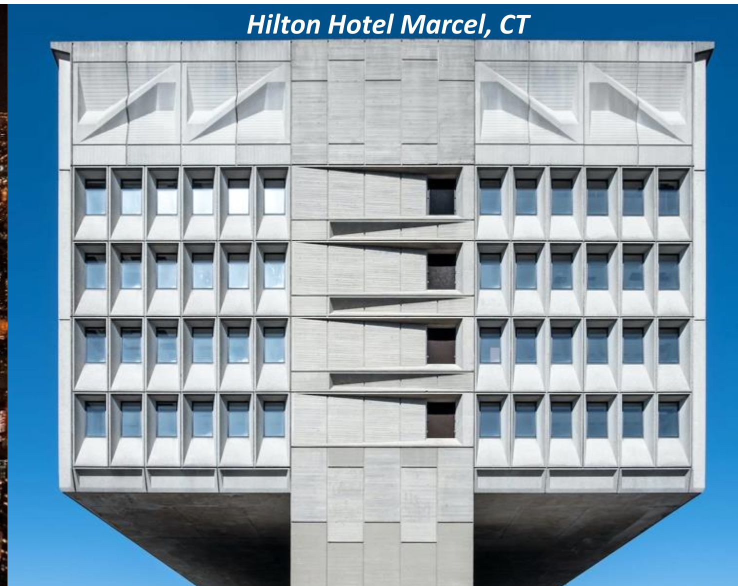
Empire State Building, NY



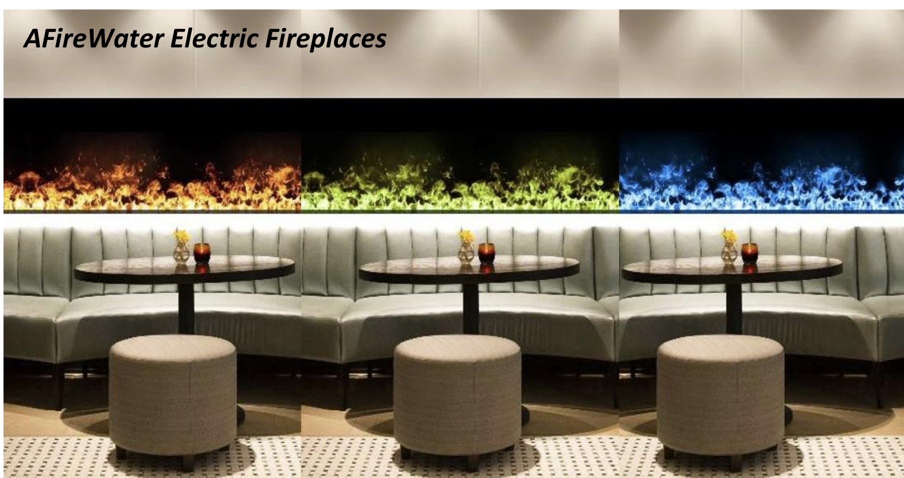
Hilton Hotel Marcel, CT

Alohilani Resort, HI

Bayview Tower, WA

Sitka Public Library, AK

A Pocket Guide to All-Electric *Retrofits* of Commercial Buildings



AFireWater Electric Fireplaces

Beach Club at Hummock Dunes, FL

A Selection of New York City Restaurants

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This report was produced for Menlo Spark, a non-profit, community-based organization that unites businesses, residents, and government partners to achieve a climate-neutral Menlo Park by 2025. Menlo Spark weaves together transformational energy, transportation, land use and building policies that promote community prosperity, bolster economic vitality, and protect civic heritage. The intent of this report is to help cities and developers everywhere embrace healthier, lower cost all-electric building construction practices.

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Introduction

The Empire State Building's planned electrification uses hydronic air source heat pumps.

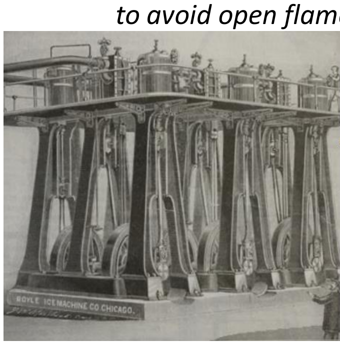
Electricity is already used for 60% of space and water heating in American commercial buildings,[1] and commercial powerhouses like Marriott, McDonalds, Microsoft or the entirety of Manhattan, commercial powerhouses are rapidly electrifying their buildings and services. Sometimes this is the result of public policy—in 2016 the city of Zurich, Switzerland started shutting off gas to the commercial and multifamily districts[2], and New York City has placed air pollution limits on buildings that will trigger electrification starting in 2024.[3] But most electrification has been the result of good business practices—electrification of space heating, boilers and services provides access to the best technology and lowers operating costs.

This "pocket guide" helps you identify trends in commercial electrification, teaches Best Practices through case studies, references nine interviews with practicing engineers, and finishes with an extensive product catalog of commercial appliances and equipment. Benefits include:

- Outdoor swimming pools using heat pumps cut bills in half.
- 25% more French fries are served per hour from electric deep fryers.
- The use of heat pumps would lower commercial buildings' greenhouse gas emissions by 44%.[4]

***Business Case Study**: BlocPower was co- founded by Donnel Baird (center) in 2011 to electrify commercial buildings in NYC like St. Bartholomew's Church in Manhattan (left), and is a new model for the existing practice of Energy Service Companies (ESCOs). BlocPower is contracted to electrify the entire town of Ithaca, NY (right) and dozens of other American cities like Milwaukee, WI and Oakland, CA.*

***A Brief Visual History of Commercial Electrification:** From L-R: The Anheuser-Busch brewery's ice machine in 1882; The world's first building air conditioner, designed by Willis Carrier, allowed accurate color prints; Young women delivering ice during WWI; An ad for office air conditioning in the 1950s; Modern cruise ships use all-electric appliances to avoid open flames on board, with electric commercial kitchens feeding up to 11,000 people a day.*



Opportunities to Increase Restaurant Sales, Safety and Skills

Restaurant are a great example of how a business can increase sales opportunities by switching to electric appliances. 85% of American restaurants use fryers. During rush hours, restaurants often struggle to serve popular fried foods quickly enough. Gas fryers are half as efficient at transferring heat as electric fryers (35% vs. 75%)[5] The faster heating means electric fryers can produce 25% more French fries per hour. Similarly, induction ranges are more than twice as efficient than gas ranges at heat transfer (35% vs. 80%), and boil water twice as fast as gas ranges. Because electric kitchens use half or less as much heat to cook food, they require half as much air conditioning, and increase staff productivity with a cooler work environment.[6]

Oysterman Seafood Bar & Kitchen: ***"The induction units… have allowed us to serve guests at a significantly faster rate. We made the switch to induction because our chefs experience far fewer burns using induction, and cleaning is easier too. We wanted to make our chefs' lives easier and keep a low turnover of staff."***[1] *Head Chef Alex Povall of Oystermen Seafood Bar & Kitchen. Twice Awarded Best Restaurant in London in 2019.*

Alinea's Chef Grant Achatz.

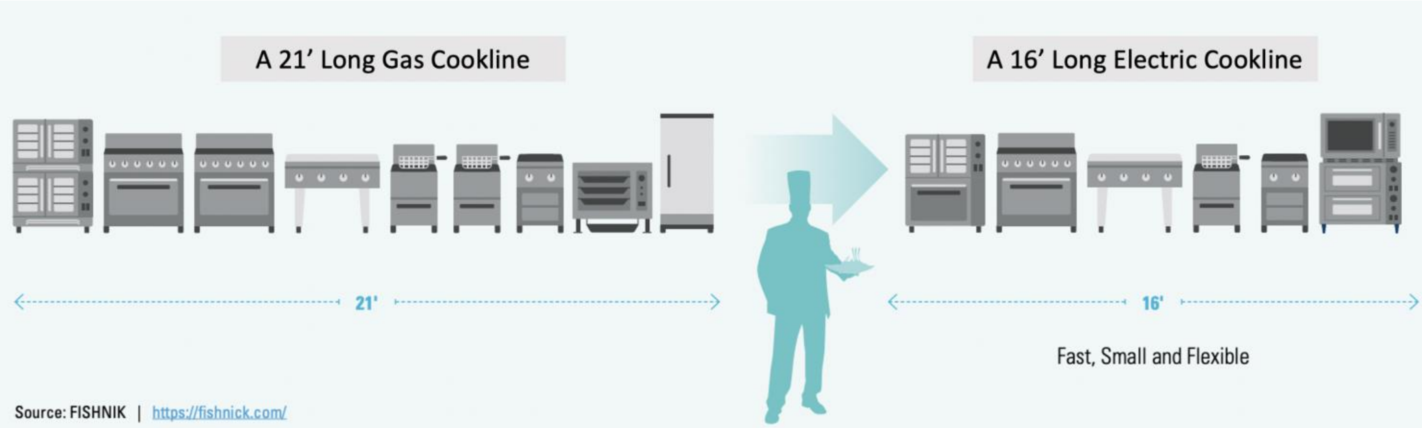
The best restaurants of the world are awarded Three Michelin Stars, charge an average of $350[7] per diner, and must demonstrate technical mastery every year to retain their rating. Chef Grant Achatz, co-Owner of Alinea in Chicago, retrofitted the Three Michelin Restaurant to all-electric, explaining: "**Technology becomes a very powerful, creative tool for us**. It gives us more ways to manipulate the food in unexpected and new ways."[8]

An artful desert at all-electric Alinea.

Chef and TikTok Star Jon Kung cooks on induction for his 1.5M followers.

Examples of professional chefs switching to induction include TikTok star Jon Kung, who explains to his 1.5 million followers, "**The best chefs have already adopted this technology. Induction provides me with the power I need, with portability and cleanliness, and lack of fumes that requires me to have a fan."**[9]

First Lady Michelle Obama and Oakland Warriors basketball star Stephen Currey danced to "Turn Down for What?" to encourage Americans to cook with vegetables while Executive Chef Comerford cooks a turnip soup called "Turnip for What?" on the White House induction range.



Electric equipment takes less space to do the same amount of cooking. The easiest way for a restaurant to expand the kitchen's cooking capacity is to replace the gas equipment with electric and free up 30% more space.

Beach Club at Hammock Dunes, Palm Coast, FL

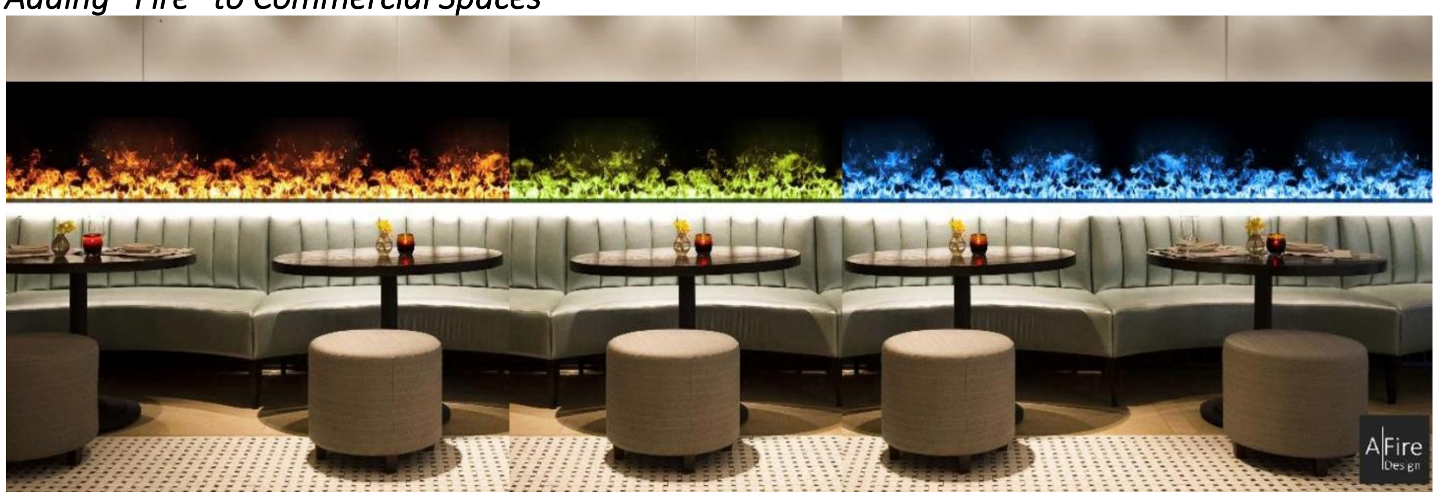
Tamarack Ski Club, Ellicottville, NY

Having Fun and Saving Money with Pool Heat Pumps

Pool and hot tub heat pumps use only 10% of the energy of a gas pool heater in the summer, and just 30% in the winter. They also lower maintenance costs from clearing clogged gas burners and cleaning sooty heat exchangers.[10]

The Beach Club at Hammock Dunes in Palm Coast, Florida, cut their pool heating bills in half by replacing the propane boilers with heat pumps, a dramatic savings for business based solely on heated water park entertainment.[11] According to Joe, the Maintenance Supervisor at the Tamarack Ski Club in Ellicottville, NY, replacing the propane boiler with a heat pump boiler reduced maintenance for the outdoor pool and hot tubs. **"Maintenance is way down, I mean, less than half what we used to do."[12]**

Adding "Fire" to Commercial Spaces



Case Study: Purser's Bar in Layton, Utah is transformed with an electric mist fireplace at the entrance in Season 7 of Bar Rescue.

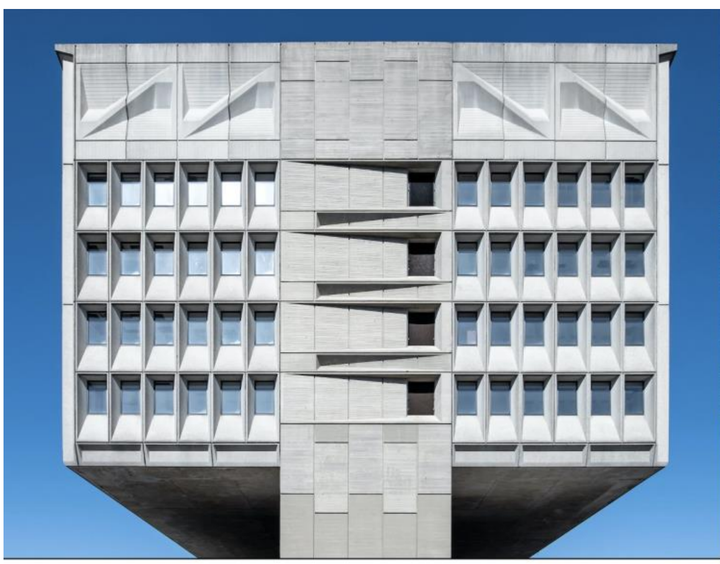
Fireplaces are a part of our favorite bars, ski lodges and more, but the gas and wood versions are expensive to retrofit into a commercial building. Mist fireplaces are less expensive, appear to be real fire, and even offer supplemental heat, but unlike gas and wood fireplaces, they can be placed anywhere and don't need venting.

The mist "flames" can be highly realistic, but a remote control can match the flame colors to those of the winning home team, a rainbow for Pride celebrants or green for St. Patrick's Day. Mist-based fireplaces are safe to touch and come with optional electric heaters to warm and entertain customers.

Mist fireplaces add ambiance and beauty.

All-Electric Leisure and Luxury

Both the world's finest old hotels and the newer Airbnb industry have committed to retrofitting to all-electric as part of their climate change reduction policies[13], which can reduce utility bills while creating fine dining, shopping malls, luxury housing and entertainment without fossil fuels.



The Marcel (above) was a Brutalist/Bauhaus office building in Connecticut and is now an all-electric Hilton with heat pumps. The Canary Islands Ritz Carlton recently retrofitted with Aermec heat pumps in its luxury hotel (top, right), while (bottom, left to right) Colmac heat pump boilers were retrofitted into the Alohilani Resort in Waikiki Beach, the Carlton Tower Hotel in Dubai, and the Asiana Plaza Hotel in Ho Chi Minh City, Vietnam.

HVAC in Commercial Buildings

Since commercial buildings vary greatly in size and zone type, there are several different configurations for heating, ventilation and air conditioning systems (HVAC). This section presents typical existing HVAC systems and discusses the various strategies to electrify them. This section was developed in part by interviews with (and in no particular order) - *John Gautrey of Integral, Brandon Gill of Taylor Engineering, Ted Tiffany of Guttman & Blaevoet, Stet Sanborn of Smith Group, Reinhard Seidl of Taylor Engineering, Scott Shell of EHHD, and Rosanna Lerma, EDesignC.*

The Most Common: Single Zone HVAC in Commercial Buildings

In California 98% of commercial buildings use at least one of the four types of Single Zone system like those seen in Table 1. It is worth noting that not all of them need to be electrified--31% of commercial buildings in California already use heat pumps for space heating and need no retrofit.[14] However, the remaining 69% of California's commercial HVAC systems need to be electrified.

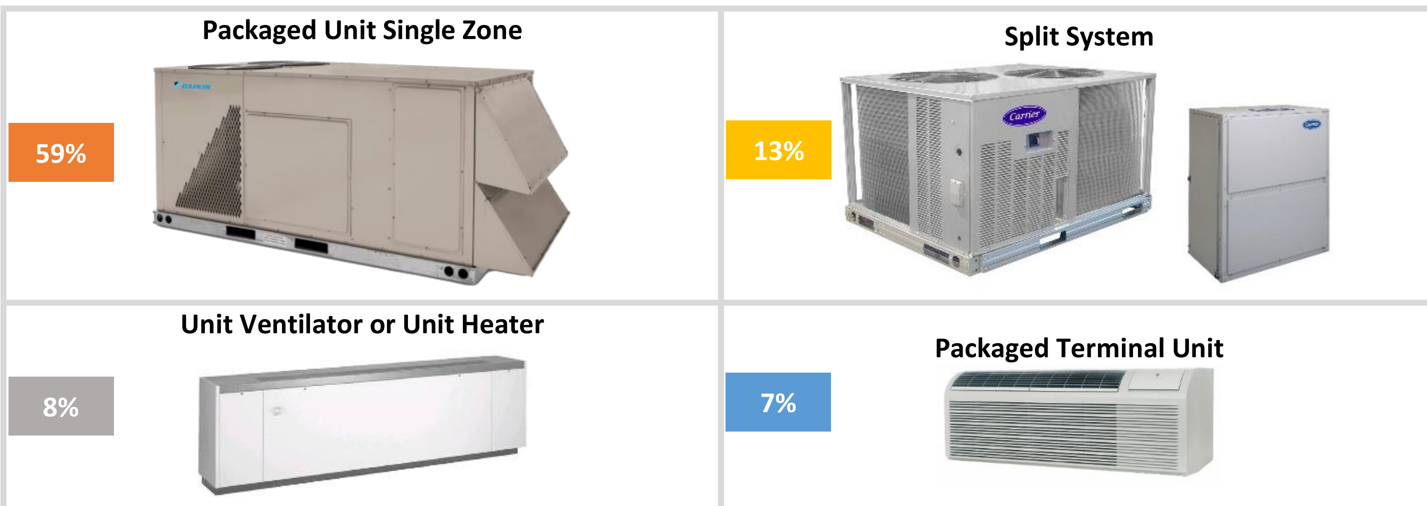


Table 1: The above four "single zone" heating system types represent 86% of the Heating systems found in California's commercial buildings in the 2014 (See Appendix A for descriptions of the equipment types).

Packaged Single Zone HVAC Systems

Typically small to medium sized commercial buildings have packaged rooftop units that provide heating and cooling via ducted blown air. In the United States the most common commercial HVAC system (46%) is packaged rooftop units,[15] while in California they are even more commonly used (59%).[16] Replacing packaged rooftop AC units with heat pumps is an uncomplicated retrofit, as they look the same and have the same needs.

Split Single Zone HVAC Systems

The second most common Heating system both nationally and in California is a "split" type, comprising 13% of commercial HVAC in California. They look similar to most home air conditioners, but bigger. The outside compressor is connected with a thin pipe of refrigerant to a single indoor fan coil that blows warm or cold air through ductwork in the building. The electric version uses a heat pump or electric resistance for Heating, but air conditioners paired with gas furnaces are also "split" systems. Replacing an Air Conditioner with gas furnace with an equivalent Heat Pump is a straight forward retrofit.

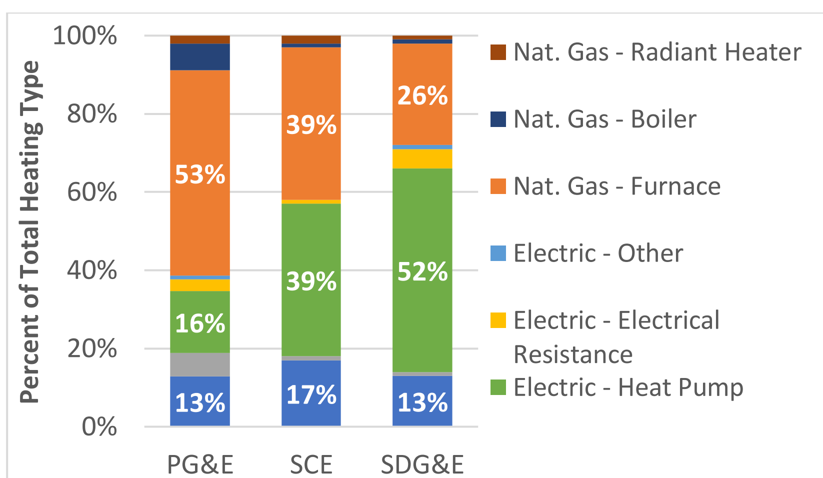
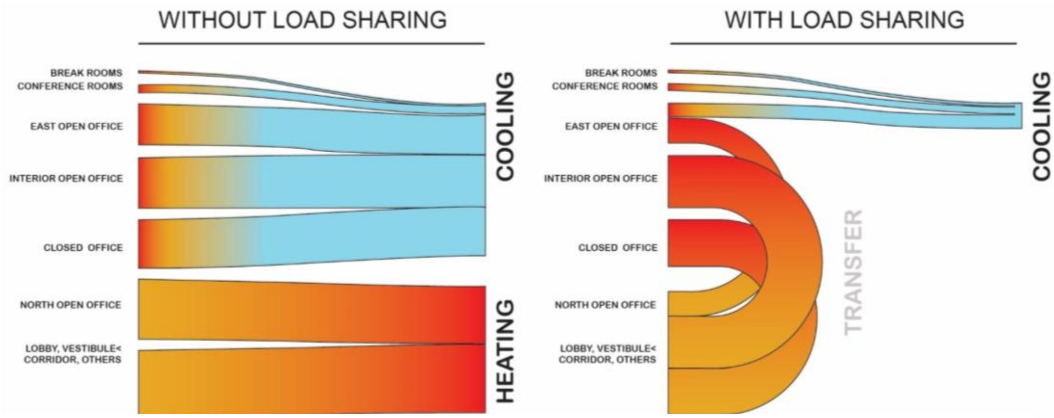


Figure 1: Heat pumps in CA commercial buildings increase from 16% to 52% as the climate warms, North to South.[17]

The Biggest Impact: Multizone HVAC in Commercial Buildings



Case Study: Multizone heat pumps can move heat from where it is being wasted to where it is needed. At 100 Avenue of the Americas in Manhattan, NY, they discovered that all of the winter space heating needed for exterior offices could be met with waste heat from air conditioning the interior core of the building during the winter. (Empire Building Playbook, April 2022. NYSERDA)

Multizone systems are found in only very largest and most diverse buildings, and comprise just 6% of all HVAC systems in California. They are often built up from multiple heat pump and storage systems with specialized tasks, requiring well-trained engineers to integrate their designs, and highly skilled installers that use tools and tactics not seen in residential-scale systems. While they pose the largest technical challenges, they are also the largest GHG reduction opportunity.

The buildings that use multizone systems are just 1% to 4% of all buildings in US cities—generally those that are larger than 20,000 square feet—yet this tiny minority of buildings produce 37% to 75% of the greenhouse gas emissions of a city's building stock.[18] These multi-zone systems deserve special study because of their outsized role in addressing climate change.

Table 2: Typical multizone commercial HVAC heating and cooling equipment.

Packaged Multizone	Built-up multizone systems	Variable Refrigerant Flow
	 	

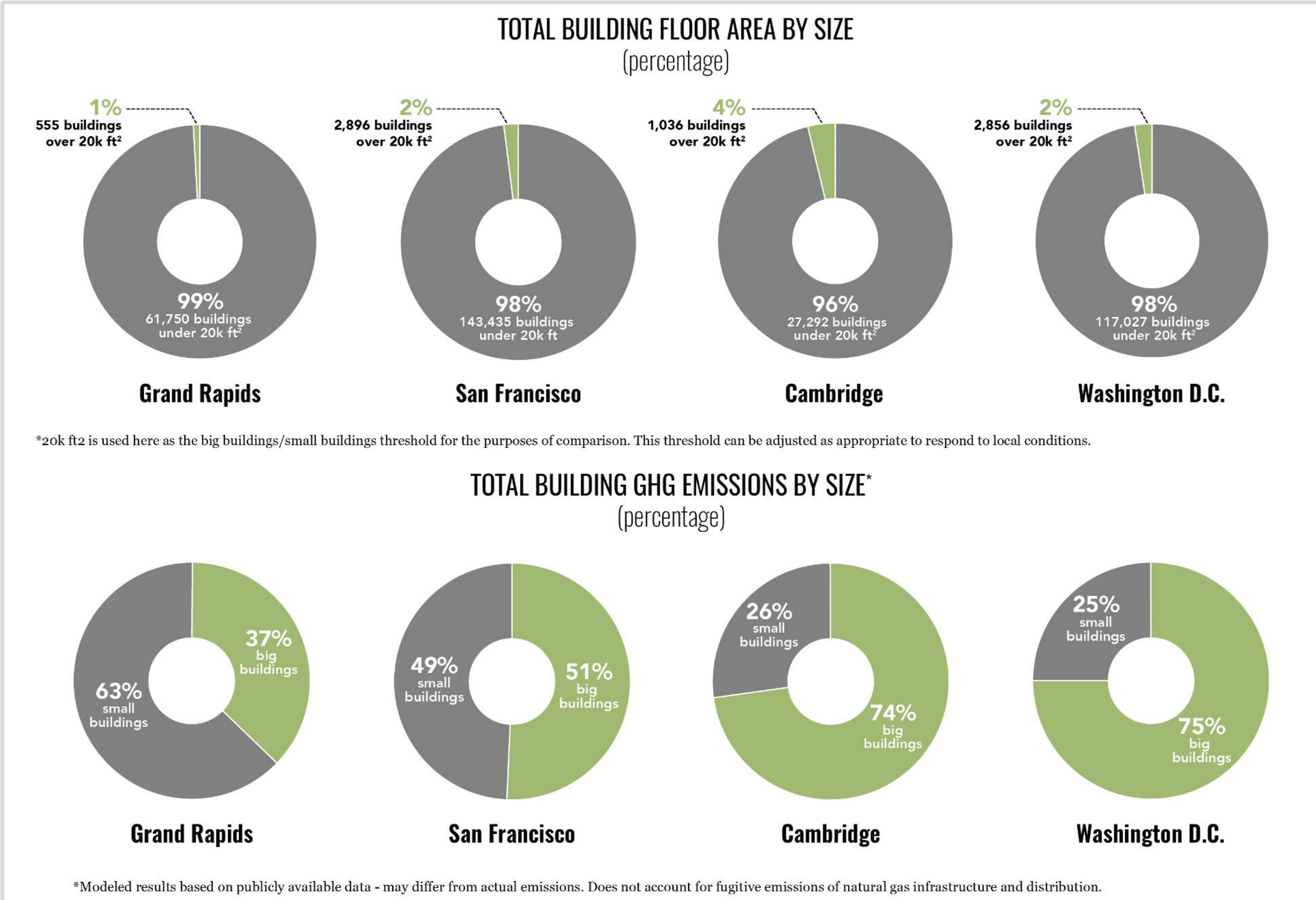


Figure 2: Architecture 2030's analysis of the disproportionate greenhouse gas emissions by buildings larger than 20,000 square feet in cities.[16]

Further breaking down the California statistic of 6% of commercial HVAC using multi zone systems, 2.4% are **two-pipe fan coil systems** which have a fan coil (ducted or not) in each zone that is heated and cooled via a chilled and hot water loops. The water loops provide heating in winter via hot water and cooling in summer via chilled water, but not both at the same time. **Four pipe fan coil systems** can deliver simultaneous heating and cooling to different zones from a heated water loop and a chilled water loop. This is common in large office buildings, campuses or hospitals, and typically have chillers and boilers to heat and cool the water. **Water loop heat pumps** are the next most common (1.5%), that also circulate a water loop throughout the building, but at each zone there is a water source heat pump that can provide heating and cooling to a space. The next are **multizone packaged systems** (1.1%) that look very similar to the single zone systems but provide heating and cooling to more zones. **Built-up multizone systems** are custom systems that include chillers, boilers, fan coils, air handlers, and cooling towers that serve multiple zones and comprise of less than 1% of California's commercial buildings.

Variable Refrigerant Flow heat pumps are 80%-90% of all installations in Eurasia,[19] and are rapidly becoming popular because they are designed to work in cold climates, which is still uncommon for many commercial scale heat pumps. These systems are so new that their saturation in the market has not yet been measured, but they – which are a more complex and bigger version of a single family mini split heat pumps - are common and are typical in high performance retrofits and new construction. In this case, the heating and cooling are delivered to the space via refrigerant, instead of air or water.

Commercial HVAC Retrofit Strategies

This section discusses in general the various strategies for electric high performance commercial HVAC systems. The HVAC system for a commercial building will depend mainly on the size of the building. Brandon Gil of Taylor Engineering, breaks down what a typical HVAC system for a commercial building may look like depending on the size of the building:

- **50-100 tons of cooling**: A smaller building with less zones would typically have rooftop units or built-up air handlers with VRF coils. (An example of this kind would be the Berkeley Mental Health Services Building discussed below.)
- **100-200 tons of cooling**: This size of building would typically have air to water heat pumps that utilize water coils (instead of DX coils like mentioned above). The heating and cooling for these water coils would be with a 4-pipe heat pump or an air source heat pump chiller. These systems can supply hot or cold water and can reject or absorb heat to and from the outside air. (An example would be the “Two Sister Buildings in Mountain View” case study, discussed more below.)
- **200 and up tons of cooling**: This is for large buildings or campuses where you can have a water-cooled system (instead of air cooled in the other two categories). Large systems are also great candidates for thermal energy storage, to store hot or cold water to use when the building needs it, not necessarily when this water is produced. Taylor Engineering has a preferred method of doing this, what they call the TIER system, discussed more below. (An example of this kind of system would be the Stanford University Campus, also discussed more below).

In addition to size, a building’s function is also important. The table below breaks down typical HVAC systems further depending on if the building is an Office, Retail or Hotel. This table is summarized from a resource by a group of industry experts that summarizes the new construction electrification strategies for all building types[20]. Note this report and table was in reference to new construction. However, this is still applicable to retrofits when the building it being gut-retrofitted, meaning all the existing mechanical infrastructure is being taken out and the whole building is being deeply revamped. In addition, this table represents the best practices of commercial HVAC design and the concepts presented within it will be referenced throughout this section.

The following sections discuss the most typical retrofit solutions for Commercial buildings, as discussed in the interviews conducted for this Guide: packaged rooftop units, variable air volume (VAV) with reheat and variable refrigerant flow (VRF) systems.

Table 3: Typical all-electric HVAC system types for new construction commercial buildings.[21]

HVAC System Type Options	Image	Description	Small Office	Large Office	Small Retail	Large Retail	Large Hotel
Central Air-to-Water Heat Pump (AWHP)		*Hydronic distribution system that uses heat pumps to heat the water to circulate to in-unit terminal space heating units*	X	X		X	X
Variable Refrigerant Flow (VRF)		*Central heat pump system with refrigerant distribution*	X	X	X	X	X
Packaged Heat Pump - Single Zone System		*Single zone packaged units each providing heating and cooling to one zone.*	X		X		
Packaged Rooftop Heat Pump		*Packaged, all-in-one system including heating, cooling, ventilation air, and return air all in a single unit.*			X	X	
Packaged Variable Air Volume (VAV) Heat Pump with Electric Resistance Reheat	 	*Packaged rooftop system typical for small offices across the United States, except with a reversing valve enabling heat pump mode and electric reheat boxes (as opposed to hydronic reheat boxes)*	X				
Water Source Heat Pump Systems		*Discharges/extracts heat from water flowing in a closed hydronic loop serving four pipe indoor coil units (most likely)*		X		X	X
Ground Source Heat Pump Systems		*Discharges/extracts heat from ground or body of water through an open/closed hydronic loop serving four pipe indoor coil units (most likely)*		X		X	X
Large Hotel Only: rooms: Ducted, Single Zone (ASHP), Or Packaged Terminal Heat Pump (PTHP) Non-rooms: Multizone ASHP	  	*ASHP: A single-guest suite heat pump ducted with outdoor condenser* *PTHP: Reversible zonal packaged air conditioners that provide heating and cooling from the same unit*					X

Packaged Rooftop Units Retrofits

> *"The biggest market if you want to make a move on actually getting gas out of commercial buildings is to target the rooftop packaged unit with easy retrofits."*
> *– **Stet Sanborn**, The Smith Group*

Packaged rooftop units are typically used in small to medium sized commercial buildings that are one to two stories and less than 50,000 square feet. This HVAC type represents a huge market and a big opportunity for decarbonizing and reducing emissions in the commercial sector. Summarizing Stet Sanborn at Smith Group, most systems of this type are simple and the least expensive option; they are constant air volume and serve a single zone with a single thermostat, so the electrification retrofit of this system is straight forward – replace the rooftop unit that has an air conditioner and gas furnace with a heat pump that does both heating and cooling, in addition to caping the gas line to the unit. No changes to the distribution system are necessary. Many manufactures make both options – the heat pump system includes a reversible valve so the system can provide heating and cooling. In colder climates they may have to be upsized to meet the heating demand. It is not typical to convert a system from a constant air volume to a variable air volume in buildings that are relatively small, with a single zone type.

John Gautrey of Integral adds (paraphrasing) that there may be some structural work needed to accommodate the heat pump because they have a slightly different footprint than a gas unit. In addition, John mentions that for non-typical commercial buildings that require more outside air, about 40%, (typical is about 20%), you will need to add extra equipment to make sure the coils do not freeze the compressors. The solution for this can be to add an electric heater to prevent freezing and add an evaporator cooler to prevent overheating, but again, this is for non-typical commercial building.

Case Study: Berkeley Mental Health Services Building[22]

Figure 3: The Berkeley Mental Health Services Building rendering of the retrofit.[23]

The retrofit of the city of Berkley's Mental Health Services building is net zero energy, following the city's commitment to environmentally responsible design. Built in 1925, it served as Rainbow Sign, Berkeley's Black Cultural Arts Center, from 1971 to 1977, and now provides mental health social services to adults in Berkley. Integral led the MEP design as well as designed signage to educate occupants about the building. The wood framed building was gutted and reprogramed, and underwent a seismic retrofit. Since it is a historic building, there were minimal changes to the envelope, however some insulation was added to improve thermal performance, and a new roof structure was added to support the additional mechanical heating, cooling and ventilation equipment and solar panels. In addition, Solatube daylighting sky lights were installed to lower the lighting energy use and improve the occupant experience.

Noah Zallen at Integral describes the project in more detail in the following paragraph. The existing HVAC system was not functioning while the building was unoccupied for a number of years. The retrofitted HVAC system includes two Daikin Rebel heat pump rooftop packages units that provide 100% outside air with a heat recovery and electric resistance back up, which provide all the heating, cooling and ventilation for the building. There are two strategies to deliver variable air volume: the first is where occupancy is consistent, there is one VAV box for several zones, with each zone having an analog thermafuser that constricts air when it's too cold or opens when the space is too warm. The second is where the zones have a higher density so there is a VAV box for each zone that is digitally controlled based on air temperature and CO2 in the spaces. This strategy results in a lot less VAV boxes with reheat than a typical application – since it is possible to utilize 100% outdoor air given the building's location and thermofusers allow for not having reheat and smaller zoning. Some challenges to this design that were overcome since it was a historic structure were that the single pane windows on the south side of the building could not be upgraded, so two rooftop units instead of one were used. In 2020, the building has not yet been fully occupied and is undergoing its final HVAC calibration.

This retrofit was a participant in the California Energy Commission research project "Integrated Whole-Building Zero Net Energy Retrofits for Small Commercial Offices", under contract EPC-16-004. The research project developed the Commercial Building Energy Saver, CBES.lbl.gov, a free tool developed to help small commercial projects identify cost effective low energy, ZNE and zero carbon designs in California. Integral Group worked with Lawrence Berkeley National Lab to develop packages of cost effective retrofit measures, which were then demonstrated in the City of Berkeley's Mental Health Services building.

Case Study: Sonoma Clean Power Headquarters[24]

Another project that utilized Diakin rooftop units with variable air volume delivery and thermofusers at the zone level is the Sonoma Clean Power Headquarters retrofit project. The two story, 15,000 square foot office building was originally built in 1979 in Downtown Santa Rosa. It was retrofitted down to the studs, with all new insulation, all new windows, all new siding and all new mechanical systems. In addition, the project includes it's own microgrid and electrical vehicle charging- which required an electrical service upgrade.

Figure 4: Sonoma Clean Power retrofitting office building.[25]

Variable Refrigerant Flow Retrofit Solutions

> "VRF was a common strategy, it has a lot of positives and a lot of negatives. The biggest problem is the refrigerant leakage, and if you look at the data it's really significant. We are tending to move away from it but we have not abandoned it completely. We are certainly not using it as much as we did three years ago, just because of the concerns of refrigerant loss." – ***John Gautrey**, Integral*

Variable refrigerant flow systems (VRF) can be attractive for commercial building retrofits because they are space compact, and refrigerant piping is flexible and can be piped around a building using less space than air ducts or hydronic piping. Adding both air ducts and hydronic piping to a project can be an expensive alternative. However, in a VRF system leaking refrigerant in long pipe lengths can be harmful to the environment (especially using R410a). With VRF, the refrigerant lines are "charged" on site which leaves more room for error and potential refrigerant leakage. Packaged units on the other hand are factory pressurized and tested for leaks, and they only have a small volume of refrigerant. Although there are potential leakage issues, VRF systems can be a cost effective way to retrofit existing buildings.

Ted, Stet, John and Brandon all say that they prefer not to use VRF – because of the refrigerant leakage global warming impacts. However, there are scenarios that they will use them. For example, Ted mentioned a project in a rural location in Northern California, where there were no contractors familiar with large central heat pump plants, but they were familiar with VRF. In addition, Ted states that they end up putting in VRF systems because it's hard to effectively communicate the global warming impacts of VRF systems (compared to centralized systems), thus a market transformation needs to happen in this space.

Brandon states when they do use VRF, they use it in a "built up" air handler with a dual fan dual duct configuration, typically for smaller commercial buildings (50-100 tons of cooling). Meaning, where instead of using the typical direct expansion (DX) coils you can use VRF coils as the source of heating and cooling. (Ted also mentioned this "built up" strategy as a better way to use VRF). In addition, Brandon states that VRF systems "do not provide any economizing benefits really, and that is one of the major flaws of most VRF systems", especially when in a climate that lends itself to economizing like coastal California.

The most common way to use VRF in a commercial building is to use the VRF system as the source of heating and cooling and pair it with a dedicated outdoor air system. Tacking on heat recovery is a more specialized system, but can reduce the amount of VRF units that you need (see Immix Law Office case study below that uses Ventacity heat recovery ventilators).

Case Study: Immix Law Office Retrofit, Portland, Oregon[26]

The Immix Law Office was moving to a new building, but was worried about the high energy bills to operate the 12,000 square foot, 1909 constructed building. By installing four Ventacity heat recovery ventilators (HRVs) they were able to reduce their equipment capacity requirements by more than 50%, and ended up replacing the nine very old, packaged rooftop units. They replaced the previous 35 tons of cooling and 43 tons of heating with a variable refrigerant flow (VRF) system with 16 tons of cooling and 18 tons of heating. Indoor air quality was also a high priority for this project because they are located in a high traffic (cars and trains) area, so the ventilation system provides excellent indoor air quality for the building's occupants. The final design includes four zones of ventilation, and eight zones of heating or cooling. Their energy bills to heat, cool and ventilate the 12,000 square foot space range from $300 to $700 a month, with outdoor temperatures ranging from 100F degrees in the summer to below freezing in the winter.

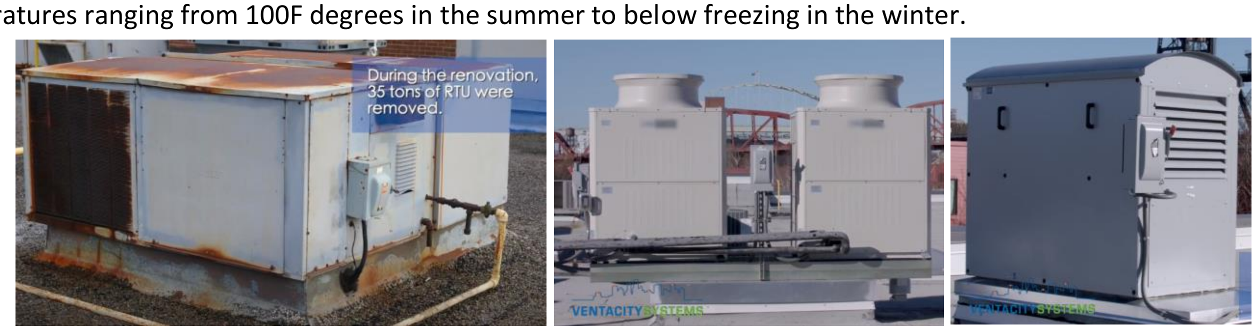


Figure 5: The before and after HVAC system of a Law Office retrofit in Portland Oregon. Old rooftop units (43 tons of heating) were replaced (left) with four heat recovery ventilators (right) and a variable refrigerant flow system (center) (18 tons of heating), reducing the buildings heating demand by 50%.[27]

Case Study: Sitka Public Library, Alaska[28]

Figure 6: The Sitka Public Library in Alaska that fuel switched from a fuel oil boiler to VRF heating system.

The island village Sitka in Alaska wanted to reduce it's dependance on expensive imported fuel oil while also reducing electricity use on the constrained hydroelectric grid. One of two of the buildings retrofitted was the Sitka Public Library, that replaced its oil boiler with efficient heat pumps, completely getting rid of the need for fossil fuels. The retrofit resulted in their "utility costs nearly cut in half, with money staying in the community rather than paying for imported fuel." In addition the building underwent other efficiency upgrades: super insulation (R-30 walls, R-50 roof, R-20 slab, triple-glazed windows), 100% LED lighting with dimming, low flow plumbing fixtures and heat pumps for water heating. Heating is now being provided by variable refrigerant flow heat pumps with radiant floor distribution in the large open spaces and wall cassettes in smaller rooms, with a dedicated outdoor air system with 80%+ energy recovery from the exhausted air. Read more on HPB magazine's website.

Variable Air Volume with Reheat Retrofits and Replacing Gas Boilers with Heat Pumps

> *"VAV with Reheat systems are the most ubiquitous commercial system out there for large buildings. If I had to call a percentage out of my head, it would be 85%-90% of every building of scale." –* ***Stet Sanborn****, Smith Group*

This section discusses the design strategies to replace gas boilers that provide reheat with electric heat pumps. **"Reheat"** refers to a coil that contains water (Figure 7) or an electric resistance coil (Figure 8) that is in each air delivery box in each zone, that heats the stream of air to the desired zone temperature. **"Variable air volume"** (VAV) means that when the zone is too warm or cool, the air being delivered is either constricted or increased to maintain a comfortable temperature. The typical configuration for reheat systems use a water loop and a gas boiler to heat it.

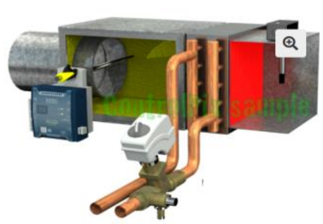


Figure 7: VAV Box with water reheat Coil.	**Figure 8: VAV Box with Electric Resistance Reheat Coil.**

It is common now for VAV with reheat systems to vary the volume of air, but also vary the temperature of the air using a **supply air reset scheme**. Essentially a reset scheme will look at the demand of the zone and the outside air temperature, then decide the best temperature and air volume to deliver to each zone, this optimizes fan speed and reduces the amount of reheat needed.

Even though variable air volume with reheat is a relatively older solution for building HVAC, it is still considered an efficient way to heat and cooling buildings today and is preferred by both Integral, Taylor Engineering and Guttmann & Blaevoet, for some of their projects. Brandon Gill of Taylor Engineering says "with advancements in efficiency over the last 10-15 years like utilizing dual max VAV logic that was added to the California energy code in 2008[29], you can reduce the need for reheat. In addition, in mild climates you can take advantage of "free" outdoor air cooling (economizing) when temperatures are favorable, making this option even more efficient." The engineering firms interviewed were predominately based in California- and Taylor Engineering works in the California San Francisco Bay area where economizing is favorable.

The biggest challenge to retrofitting variable air volume systems with boiler reheat to use a heat pump instead is that the systems were originally designed for 160-180F water delivery temperature- which has been the typical design range for the past 20 years. This is a challenge because typical air source heat pumps produce water only up to 120 to 130F.

Instead of using a gas boiler for reheat hot water, other options include:

- **Using a Typical Air-to-Water Heat Pump:** Turn down the reheat water loop temperature to 120-130F and use a typical air to water heat pump, with existing fan coils or making minor adjustments to the fan coils. Can provide a backup electric resistance boiler if heat pumps cannot provide enough heat for coldest times of the year.

- **Using a High-Temperature Air-to-Water Heat Pump:** Use the same reheat water temperature and use a newer air source heat pump. Examples of heat pumps that exist that can produce high temperature water are Mayekawa Unimo Series[30] (up to 194F water) and Lync Aegis by Watts[31] (up to 185F water). Although possible solutions, these heat pumps are newer to the market and are usually more expensive to purchase.

- **Using Electric Resistance:** Instead of using a hot water loop reheat, utilize electric resistance reheat. This would be for a gut retrofit project where most of the existing system is already being replaced, and this includes adding electrical capacity where necessary in the zone to power the new electric resistance coils. The motivation for this strategy, which was actually the preferred way to provide reheat before gas boilers became more popular, is because reheating with a boiler isn't as efficient as it might seem. There is a huge amount of heat loss through the pipes as the hot water is distributed to the reheat coils throughout the building. The Center for the Built Environment did a study on the energy loss in hot water reheat systems specifically in VAV with reheat. And found that an 11,000 m2 building with 98 terminal reheat coils only used about 21% of the converted gas energy for the reheat. In addition, the heat distribution losses from the boiler to the reheat systems was about 44%.[32] However, reheat can be optimized to be comparably efficient, with the appropriate reset schemes that reduce the amount of reheat needed, so in a project it's not reasonable to replace piping, replacing the boiler one to one with a heat pump can be an effective solution.

- **Using a Cascading Heat Pump Configuration (Air-to-Water then Water-to-Water heat pumps):** Examples of this strategy are outlined in a presentation by Johan Martensson at Transom Corporation, where he discusses a theoretical system that produce 180F degree water at -30F ambient air with a COP of 2.2-2.4[33]. They have designed 16 systems using this cascading strategy (with varying ambient air design and supply temperatures) going from air source heat pumps to water source heat pumps. This strategy is applicable for radiators where temperatures cannot be turned down and in colder climates.

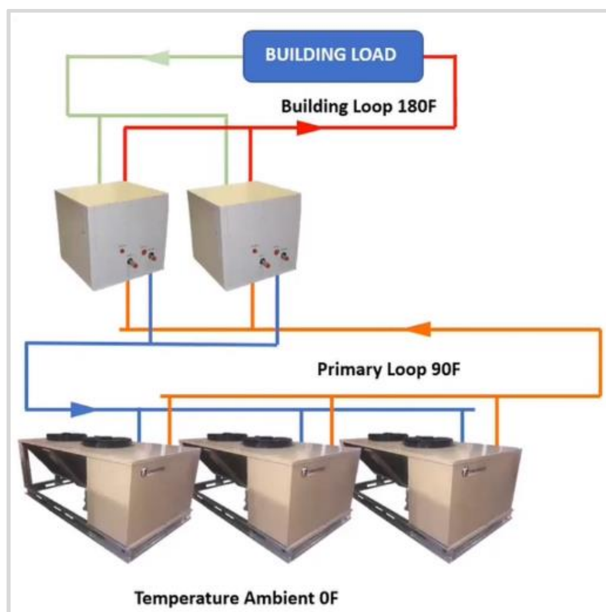


Figure 9: Transom cascading system to product 180F degrees at 0F outdoor air.

- **Using a Cascading Heat Pump Configuration with Thermal Energy Storage and Heat Recovery Chillers:** Taylor Engineering writes about their heating strategy for electrification of large buildings, what they name the Time Independent Energy Recovery (TIER) design, that incorporates thermal energy storage and heat recovery to improve existing strategies of all-electric, large building HVAC design.[35] In essence, their suggested and preferred approach is to utilize condenser water storage (60-80F) with cooling only chillers, heat recovery chillers, and "trim" air source heat pumps (Figure 10). Alternatively, electric boilers can be used as the trim heat source instead of air source heat pumps, where space is limited. (Note that large water storage tanks can take up a lot of space, so utilizing storage is more applicable to new construction).

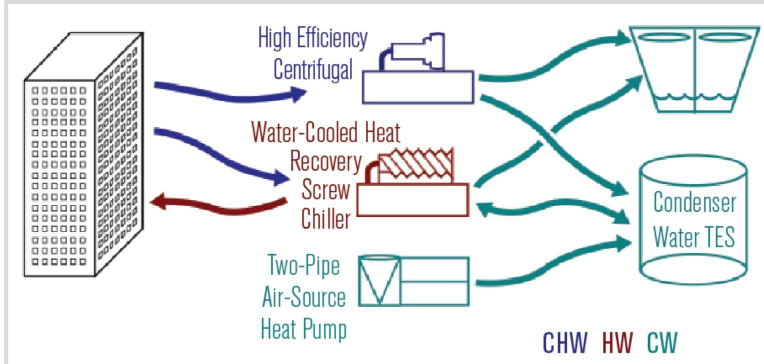


Figure 10: The energy transfer of a condenser water TIER system, as outlined in Taylor Engineering ASHRAE article.[34] (TES = thermal energy storage)

Case Study: Typical Air-to-Water Heat Pumps: Two Sister Buildings in Mountain View, California

Reinhard Seidl discusses one of his electrification projects of two buildings located in Mountain View California. The two buildings were similar in their original design – with large air-cooled packaged units on the roof, with chillers and boilers suppling the heating and cooling to the building's spaces. One building had two 60-ton chillers and the other had three 60-ton chillers, both with a boiler providing reheat.

> *"In most cases typical heat pumps that can produce 120-degree water will actually work fine in buildings with an existing boiler reheat system, as long as they have two row coils, which most buildings do."*
> *– **Reinhard Seidl**, Taylor Engineering*

Both buildings retrofitted to use heat pumps instead of a boiler for their reheat systems. One used a heat recovery 4-pipe heat pump, and one kept their original chillers and went with a heating only heat pump. In the building that kept the heating and cooling as separate heat pumps – it was found that it was a less expensive strategy to replace the air-cooled chillers on the roof with newer, more efficient ones because they were at the end of their life - than going with a 4-pipe heat pump.

Analysis was done to determine the best route to retrofit the systems and initially there was some hesitancy from the design team to use heat pumps for heating. The main issue was that the reheat water loop was designed for 180F water, and the new heat pumps can only provide 120F. So in April, the design team did a turn down test, and turned the water down to 120 F to see if the spaces were still getting the optimal temperatures at each zone and if the existing coils can deliver the heat needed through a typical morning warm up test. The test went well, and the lower temperatures could provide sufficient heat, and it only lengthened the warm up cycle of the buildings by about a half hour. From this test they found that some zones needed maintenance on their coils (bad actuators on their reheat valves) and this was the only reason that any zone was too cold. As an aside, Reinhard Seidl states that older systems were actually designed for atmospheric boilers that have to operate at 180F or they will corrode at lower temperatures (unlike stainless steel condensing boilers today). In reality, the coils themselves only need a temperature difference of 30 degrees, so in theory you can supply water down to 90 degrees.

The next big decision of the design team was to decide whether to provide a back up electric resistance water heater as well. From Taylor Engineering's experience it is typical that a heat pump will carry the load most of the time, and the electric resistance heater will boost the capacity when temperatures are low. Based on the turn down test it was determined that they would not need electric resistance back up, however the design team did all the engineering checks and determined there was enough power if the client would like to put in electric resistance back up at a later date.

In the several projects that Taylor Engineer has done where there is an existing boiler reheat system – they have successfully been able to turn down the hot water loop temperature, so long as the coils at the zones have two rows, which all the projects they have worked on do. Where you may need to make a change to a VAV box, Reinhard states, that "it is not that difficult to take the box apart and put an oversized coil in it with two duct transition pieces and basically give it a bigger coil in case it needs it." However, he says, "in most cases typical heat pumps that can produce 120 degrees will actually work fine in VAV reheat buildings as long as they have two row coils." In the case where you have single row coils, which is not as common, you would have to retrofit each VAV box, which would be costly but a manageable.

Adding to this, Brandon Gil of Taylor Engineering states (paraphrasing) that most systems have been oversized in California and will have two row coils already and two row coils are typical for manufactures to offer. Also, newer high efficiency condensing boilers are more efficient with lower incoming water temperatures, so two row coils are typically specified for these as well. Brandon Gil of Taylor Engineering says, "adding three or four row reheat coils is generally a viable retrofit strategy for a lot of buildings" and the additional static pressure added to the air handler is usually not a problem because most engineers are conservative when designing their supply fans.

Case Study: A City College in Northern California

John Gautrey of Integral's perspective on boiler retrofits is that it is tough in a partial retrofit but it can be done. He discusses one project they are working on for a City Collage- they want to electrify to an all-electric central plant by replacing their existing boilers with heat pumps. The main issue they wanted to avoid was to not have to renovate each building to accommodate the lower temperatures that heat pumps provide. The solution for this was to look at each coil individually- by running analyses with the manufacturer under the new operating parameters to make sure the coils could handle the new flow rates. With this and tweaks to the temperature of the central plant, they were able to show that heat pumps will work without a lot of modifications to the existing equipment. The only equipment they did have to change were some of the piping controls valves, but that was all. John attributes the less invasive retrofit to the fact that coils are typically oversized in the more temperate climates of California, so the existing system was able to provide enough heat even at lower temperatures. In addition the heat pump central plant at the College can also recover waste heat from the chilled water system to generate hot water, which increases the central plant efficiency. John estimated that "pushing the chilled water temperature up and the hot water temperature down makes the plant exceedingly efficient, you can get COPs up to 7.0", however you are limited in what recovery temperature you can get.

Case Study: Office to Laboratory Retrofit

Typical VAV with water loop reheat HVAC systems are becoming common again for retrofits, particularly retrofits where the existing building is being deeply retrofitted and gutted, so it is like a new building. Often a "gut" retrofit is motived by a major occupancy and building type change- along with this it is typical to replace all the interior furnishing and take out the existing mechanical work. For example, a medical company is retrofitting one of their buildings from a traditional office building to a lab building, so the new building required new mechanical systems and new zoning. For this project the mechanical system chosen was a conventional variable air volume with reheat, with an advanced heat pump central plant.

Case Study: Vancouver City Hall 4-pipe heat pump retrofit (2014-2017 Phase I, Phase II and Phase II ongoing)[36]

Figure 11: Vancouver city hall and the Aermec 4-pipe heat pump installed and being installed with a crane.

The Vancouver City Hall campus has retrofitted its facility with a highly efficient Air Source Heat Pump (ASHP) for space heating and cooling and domestic hot water. As stated in the study, The City of Vancouver has “plans to achieve 100% renewable energy and zero emissions in its own facilities by 2040”. The following list are three pillars that were focused on as stated in the case study:

1. Build new City-owned facilities to zero emissions standards from 2018 onwards
2. Upgrade existing facilities to make them more energy efficient and converting natural gas to high-efficiency electric heating
3. Connect close-by civic facilities to low carbon Neighborhood Renewable Energy systems

Another major reason for the retrofit of the City Hall campus was for seismic safety issues. The retrofit is divided into three phases (Phase I, Phase II, and Phase III). During Phase 1 of the project, which was develop between 2014-fall of 2017, included demolition on the East Wing and evaluation of different heating and cooling systems. A few heating and cooling systems such as, “a helical rotary chiller with fluid based cooling tower (a like-for-like replacement), an air-cooled chiller, and air-cooled chiller with a desuperheater, and a heat recovery air source heat pump (ASHP)” were evaluated in 2015. In 2016 the ASHP was decided on as the most energy efficient solution. Demolition of the East Wing was completed in 2016 and by 2017 the new ASHP was installed.

The City of Vancouver selected the AERMEC NPR ASHP for their space heating and cooling source and DHW preheat. This system was ultimately selected for the following reasons. Due to it’s heat recovery, this specific model is very efficient with a Total Efficiency Ratio TER of 6.3. In addition, this system was selected due to it’s capabilities to simultaneously and independently be used to provide space heating, space cooling, and DHW and it had been successfully installed in another building and tested.

The systems design for the Vancouver City Hall is a four-pipe system with the AERMEC ASHP as the main heating a cooling source. As the study states, “The equipment has four different operating modes: it pulls heat from the air or from the air of from the cooling loop and sends the heat to either the space heating or DHW system; excess heat can be rejected to the air”. However, the design does have its limitations during very cold weather. The supply water temperature that is delivered by the ASHP is much cooler than the building’s distribution system hot water supply temperature. During this cool weather a gas boiler is used for back-up heat.

The total cost of installation for the system was $534K with an additional fee of $138K for the ASHP equipment, installation, adding DHW preheat, piping, and controls. The life span of the system is expected to be 15 to 20 years. For the first two phases, the retrofit of the project estimates to decrease the annual consumption of natural gas by 45% and electricity use increased by 6%. The annual energy cost savings is $20,000 for Vancouver City Hall and the GHG emissions is expected to decrease by 34%.

Modification and calibration of the system will be done during Phase II. In Phase III the ASHP heating and cooling system will be completed, and, in this phase, a Dedicated Outdoor Air System (DOAS) will be installed in the entire building. Phase III may be completed by 2030.

Case Study: (New Construction) Bay Area Laboratory, heating load electrification[37]

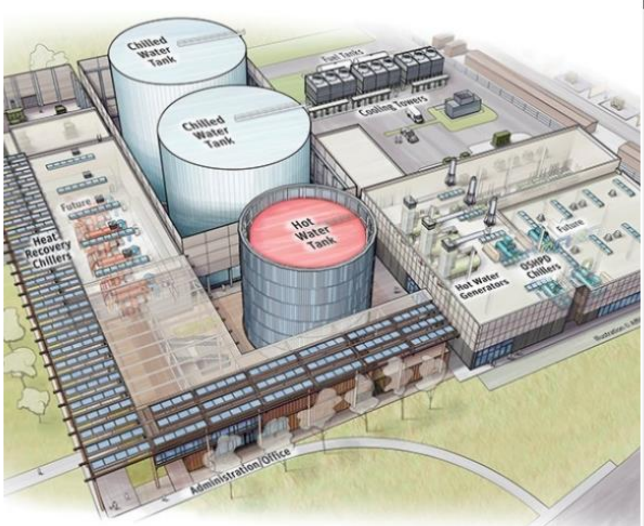
A study done for a new laboratory project in the Bay Area has summarized the energy efficiency measures to take to fully electrify the building. The building is a 7-story mix of "60% laboratory space and 40% office space" (Gilles and Gunther, 2021). The building is mostly heating dominated due to the Bay area mild climate and a larger percent of laboratory space. Therefore, high air change rates for laboratory spaces is needed, 100% outside air (OA), and reheat will be provided at each zone.

The initial design included a high-efficient gas-fired boiler to provide hot water for space heating and domestic hot water (DHW) until the design team further investigated the steps necessary to electrify the systems in the building. They also integrated energy efficiency measures such as, "high-performing window glazing and wall construction, decoupled ventilation and space conditioning for the office spaces to reduce reheat loads, auto sash closers on fume hoods, and variable flow rate exhaust fans with exhaust air velocity and plume height varied based on measured wind speed" (Gilles and Gunther, 2021). Electrifying the DHW system was an easy modification as the design team switched from a gas-fired water heater to an air source heat pump (ASHP).

As for space heating and cooling, the initial sources of space cooling and heating systems were water-cooled chillers and high-efficient gas-fired boilers. The Design team's analysis found that "air source heat pumps would have provided a better method of electrification, however when compared to California's Title 24 Energy Code, air source heat pumps still would result in and energy penalty when compared to the Code baseline" (Gilles and Gunther, 2021). Further analysis was done using annual heating and cooling load profiles and was discovered that 48% of the annual heating demand would be electrified by using a heat recovery chiller. **Ultimately, the design team was able to electrify more than 99% of the annual heating demand by incorporating a heat recovery chiller with energy recovery from the exhaust air.** A small electric boiler was included to provide the remaining heating demand. The changes have not only reduced the amount of energy consumed, but from the study the found that it was, "water efficient as it eliminated cooling towers completely from the project" (Gilles and Gunther, 2021).

Case Study: The University of California and Stanford University

In 2019 the 137 million square feet of University of California buildings will no longer use fossil fuels in major retrofits, nor in new construction at any of the ten campuses. By 2025 the entire UC system will be carbon neutral—6000 buildings. Silicon Valley's Stanford University has already electrified most of their campus of 12 million square feet of buildings with a central water source heat pump with one hot storage tank and two cold water tanks. The heat exchanger produces hot water by pulling heat from groundwater, reducing heating energy needs by 93%, and the combined efficiencies of the new system reduce water use by 70%.[40] The system is so efficient because it utilizes a significant amount of heat recovery, a yearly profile in the figure below shows that most of the campus's load is met by heat recovery.



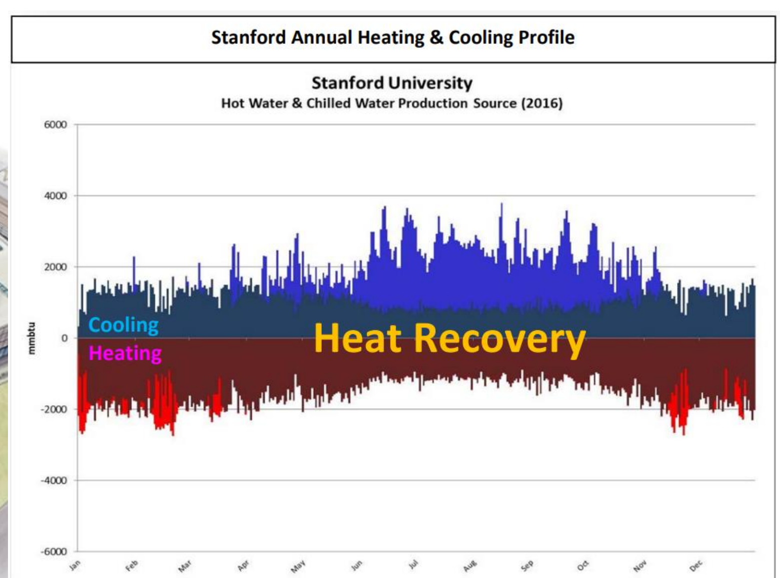


Figure 12: The Stanford Energy System Innovation (SESI) diagram[38] and the annual heating and cooling profile.[39]

Additional All-Electric Commercial Retrofits[41]

The Exploratorium: Science Museum
San Francisco, CA, 200,000 sq.ft., ZNE expected
Architect: EHDD, MEP: Integral Group

Pier 70, Building 12: Muti-use
San Francisco, CA,
MEP BOD: Point Energy Innovations

LinkedIn: Office
Sunnyvale, CA, 40,000 sq.ft.,
Architect: Studios Architecture, MEP: Integral Group

435 Indio: Office
Sunnyvale CA, 31,000 sq.ft., ZNE, Zero Carbon,
Architect: RMW, MEP: Integral Group

415 N. Mathilda: Office
Sunnyvale, CA, 33,750 sq.ft., NZE, Zero Carbon,
Architect: Studio G, MEP: Integral Group

AP+I Office: Office
Mountain View, CA, 14,300 sq.ft., NZE, Zero Carbon,
Architect: AP+I, MEP: Integral Group

380 N. Pastoria: Office
Mountain View, CA, 42,000 sq.ft., NZE, Zero Carbon, Architect: WRNS Studio, MEP: Integral Group

IBEW Local 595: ZNE Center
San Leandro, CA, 46,000 sq.ft., NZE,
Architect: FCGA, MEP: ACCO

Heat Pump Water Heating in Commercial Buildings

This section was developed from interviews with Evan Green a Research Engineer at Ecotope, and Brain Culler the General Manager of Small Planet Supply, and discusses the best practices of centralized heat pump water heating for domestic hot water (DHW) in commercial buildings.

The biggest benefits of using HPWHs for DHW in commercial buildings is the ability to electrify the water heating load, therefore reducing a building's greenhouse gas emissions by not using gas boilers. HPWHs are also much more efficient – they are roughly 300% more efficient than gas boilers and electric resistance water heaters, which can decrease operating costs. In addition, Evan Green at Ecotope states that, "the inherent storage that's paired with heat pump water heaters provides capabilities with load shifting as well." Meaning that electricity use can be shifted to when electricity prices are lower at different times of the day by storing hot water to use at the desired times.

When regarding water based commercial space heating systems, space heating and domestic hot water heating (DHW) in commercial buildings are typically divided in two systems. DHW typically is a different system because potable water requirements can increase system costs, so it can be cost effective to have a smaller system dedicated just for domestic hot water. Also, the temperature requirements have historically been different as well, many commercial buildings that use hot water for space heating use temperatures up to 180F, where water for domestic hot water is usually around 125 to 140F. This leads to commercial buildings generally needing smaller capacity of air to water heat pumps for domestic water heating than the size of heat pumps they need for space conditioning. There are advantages and disadvantages for combining and separating the two heating functions, and both Evan and Brian have seen systems designed both ways. The focus of this section is on dedicated HPWH systems for domestic hot water production.

Challenges with retrofitting HPWHs

There are three major challenges with retrofitting heat pump water heaters, from a design perspective. **Space** – When designing a HPWH system to match the previous heating capacity of the gas system, this usually results in more devices to provide the required amount of heating, and they are usually larger in size than gas boilers. In addition, centralized large HPWH systems require a lot more storage, so fitting the extra storage tanks and the heat pumps themselves in an existing mechanical room can be a challenge. **Electrical capacity** – the existing mechanical room electrical panels are sized for the electrical load of the boiler, and whatever miscellaneous loads are in this room, like lights and outlets, so often times a panel upgrade is needed, or "you have to do a lot of critical thinking on how much heat pump you can actually install based on the existing electrical capacity", says Evan. **Air flow requirements**– HPWHs also require enough a good amount of air flow to sufficiently pull heat out of the air. Existing boilers typically have a flue going out of the building, but these are generally not big enough. A solution for this is to locate the heat pumps outside, but if they are on the roof, then you must consider the additional weight that the roof was not designed for, which can introduce the need for a structural engineer. From the owner's perspective, the capital cost for a new heat pump water heater can be a major prohibiting factor as well. However, recent incentives in California have expanded their reach, so utilizing them can make HPWHs more accessible for more owners.

Solutions to HPWH Retrofit Challenges

The shortest-term solution for these challenges is a recent innovation in the industry called "skid" packaged HPWH systems. This is a factory-built packaged HPWH system that includes the heat pumps, storage, and the enclosure they require. They are pre-plumbed and wired, so you can place them outside on top of the building or next to it. This speeds up the retrofit process and reduces the amount of engineering needed by contractors by providing a more plug and play solution. The packaged design also allows designers who aren't familiar with the nitty gritty of HPWH design to specify them in their projects. A few products available are shown in Table 4 below. There are some challenges with skid systems, like having a constrained overall dimension that now needs to fit at the project site somewhere. The applicability of these systems depends on the project itself, and maybe a decentralized custom solution is more appropriate.

Table 4: Available packaged heat pump water heater "skid" systems.

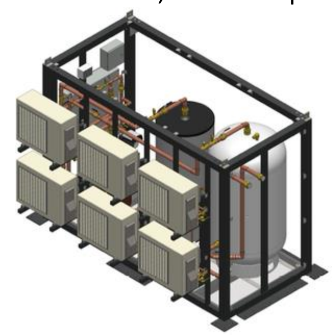
Nyle[42]

Colmac[43]

Lync[44]

Origin by Steffes[45]
(Mitsubishi CO2 heat pump)

WaterDrop by Small Planet Supply[46]
(SANCO2 ECO2, CO2 heat pump)



In talking with Brian Culler of Small Plant Supply he discussed how their skid system will address these challenges. A long with being able to place the packaged system on the roof, it can also "simplify things with a single electrical drop for the skid, it can make it easier to find a power supply and may not require another electrical panel to be installed. They can find electrical capacity elsewhere in the building and run a feeder line to our panel." In their particular skid system they use the ECO2 heat pumps by SANCO2 so it they can "distribute multiple plants throughout the building instead of just a large central plant, which distributes the equipment but also the electrical load, and maybe doesn't have to fit in the traditional mechanical room." As an example, they had a project that broke their centralize water heating network and system in half, so one skid was on the roof and one was in the basement.

> *"Our standard waterdrop configuration has a primary storage, a swing tank, mixing valve, circulator pump and heat pumps. So, they have everything, the whole hot water plant and mechanical room are on the skid with controls, so you can set it, connect the water pipes and electrical and its ready to go." –* ***Brian Culler****, Small Planet Supply*

Small Planet Supply provides redundancy by using electric resistance in the swing tank, that can back up the heat pumps by providing more capacity for the system when necessary or provide hot water if all the heat pumps malfunction. In addition, because they use multiple smaller units (the ECO2 heat pump), this creates redundancy as well, if one heat pump goes offline, then there is still the bulk of the generation capacity available. Brian Culler also points out that because the SANCO2 ECO2 heat pumps have been used for residential applications for so long – it has made them very reliable and easy to apply to commercial applications, because there is little to no maintenance on them. Another benefit of the modular design is that if one heat pump needs maintenance, any contractor can drop in a new replacement unit, without having a specialized contractor to come to the site, open the machine, and work on the specific components. The modular design also allows their skid to be applied to "a single bathroom up to entire buildings" says Brian. The "smaller output units give us a lot more flexibility in the output capacity, so we can match it to any small to medium sized building in a single skid system, and large buildings would take a couple skids." Small Planet Supply works with their clients from the "initial inquiry to the installation through the verification and startup of the system" and will work with the client to select the right sized skid or help develop a custom solution.

Best practices of HPWH Design

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[47] 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 the products and practice for designing commercial hot water systems using heat pumps. Below is helpful guidance from the engineers at Ecotope of Seattle, the most experienced designers of central domestic hot water heat pumps in North America.

Heat pumps are not boilers. Do not oversize the central heat pump up to the same recovery rate and capacity as a boiler, this leads to both higher construction costs and equipment failure. Correct sizing of a heat pump water heater will consider longer recovery times and thus include more water storage. Utilize Ecotope's Ecosizer to size your project's heat pump water heater system. The calculator provides the proper sizes of storage and of heating capacity of the heat pumps.

> *"The challenge when replacing a boiler with a heat pump when it comes to sizing, contractors will say that there is a 400,000 BTU boiler so we are going to replace this with a 400,000 BTU heat pumps, they find that they need 8 or 9 heat pumps to replace this one boiler, when in reality you have to flip the sizing on its head and size it specifically for a heat pump water heater." – **Evan Green**, Ecotope*

Design Conditions, Heat Pump Selection, and Electric Resistance Backup

The correct design of the HPWH system also depends on the climate of where the building is located, and the type of heat pump the project is using. For example, HPWHs that use CO2 as the refrigerant can operate in much lower temperatures. As an example, a building that has a 99.6% design temperature of 32F, using a CO2 heat pump you can meet the demand at this design condition, but with another type of heat pump that stops working at 40F, you will need electric resistance back up to meet the demand of the building for a few hours out of the year. Adding to this, and summarizing a presentation by Yohan Martensson of Transom Corporation, choosing the right design conditions depends on the project – he gives an example where a project changed it's design temperature from 15F to 25F, which reduced the heat pump capacity needed by 34%. There were only 63 hours out of the year they needed additional capacity so the design decided to go with a backup electric resistance boiler for these additional hours, which ended up being a more cost effective strategy. (Note that Yohan was referring to an HVAC system design, but these sizing best practices can be applied to both HVAC and DHW systems)

> Use the **Ecosizer** to design heat pump water heating system for your Multifamily project: *https://ecosizer.ecotope.com/sizer/*

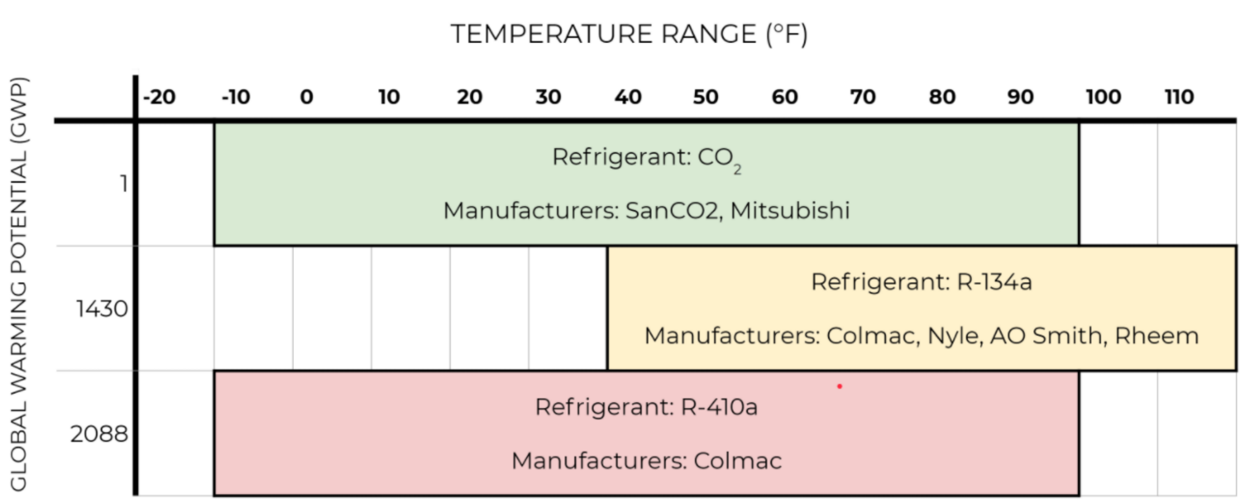


Figure 13: The temperature range of typical refrigerants that are in heat pump water heaters. Image by Ecotope[48]

Split the pipe recirculation heat loss load from the usage load. Temperature maintenance of the recirculation loop can be a high energy use in large hot water systems, where the piping network sprawls throughout a large building. Separating this load from the primary hot water heating creates a more efficient system by improving thermal stratification across the storage tanks of the system. This separation of duties allows the heat pumps to receive their optimal temperature of water. Separating the recirculation heating load can be done with a "swing" or by a "parallel loop" tank (Figure 14).

In the context of retrofits, if you have an existing system that is still in good working condition, you can use it as the swing tank system. This can be a good strategy to build comfortability with the new heat pump technology for some building owners. In the end the system will still be using gas, but much less, and be an overall much more efficient system.

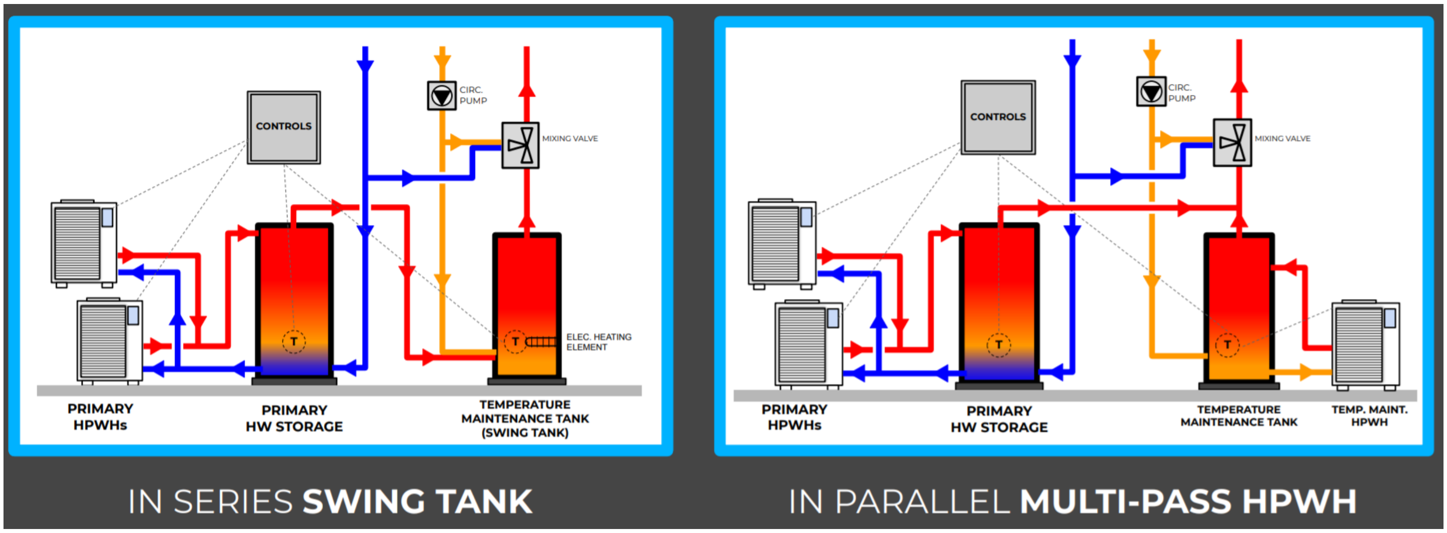


Figure 14: The best practice designs of separating the temperature maintenance load from the primary hot water load. Image by Ecotope.[49]

Temperature maintenance of recirculating water is an ideal task for "multi-pass" heat pumps that handle 110F incoming water (e.g. Aermec, Daiken) and perform 10F temperature bump-ups. Meeting primary peak loads is a task 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 50F to 150F, examples of both are show in Figure 15.

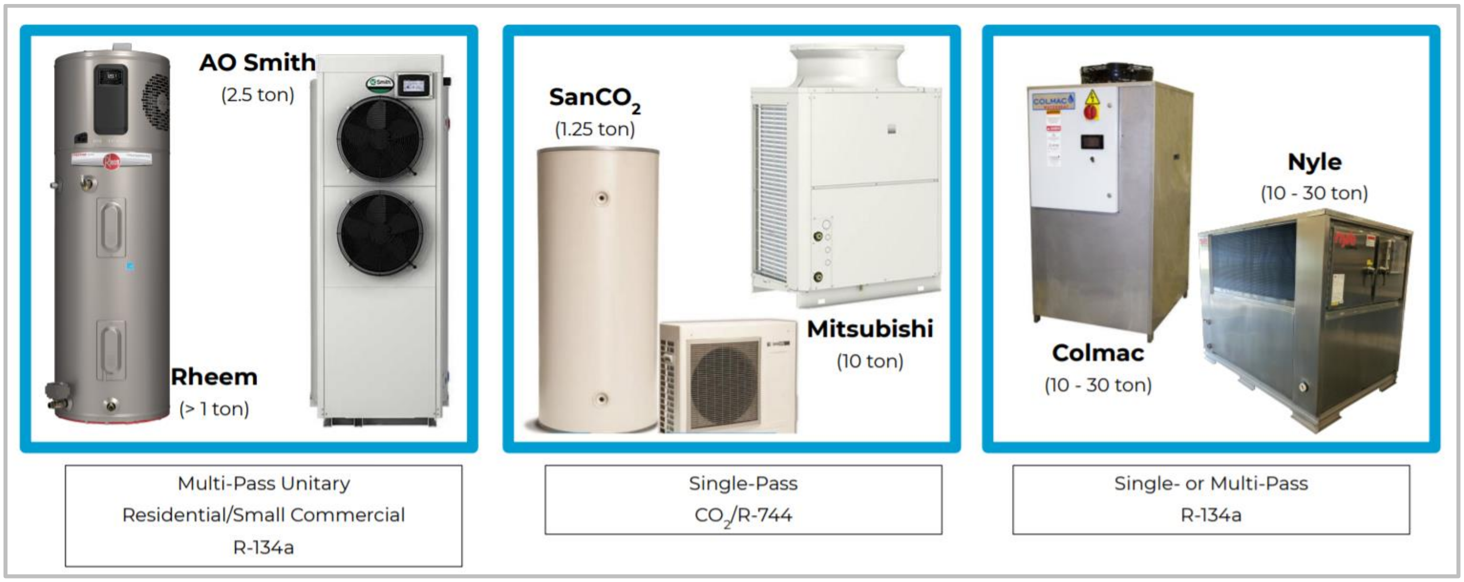


Figure 15: The categories of heat pump water heaters, multi-pass, single-pass and single- or multi-pass. Image by Ecotope.[50]

Provide redundancy in heat pumps and choose electric resistance storage tanks for a durable, dependable design for the eventuality that system components need maintenance. Using 2-4 smaller heat pumps provides more resilience and staging opportunities than using a single large heat pump.

*"Until there is more reliability and repeatability in heat pump water heater systems, electric resistance is pretty important. It's worth to have that extra back up so occupants have hot water 365 days out of the year, as they deserve." – **Evan Green**, Ecotope*

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. In addition, utilizing more efficient pipe sizing methods can significantly reduce pipe sizes and heat losses, like Appendix M of the Uniform Plumbing Code. (Note that Appendix M is for single family and multifamily homes, but it still highlights the importance of right-sizing piping).

Install "heat traps" on both hot and cold water sides of storage tanks to prevent migration and mixing.

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. It is typical that a system will be malfunctioning (whether HVAC or water heater, etc), without the use of monitoring equipment it can be hard to pinpoint issues or know there are issues to begin with. Have the appropriate alarms set up so you know that the heat pumps are not functioning.

Collaboration with the Manufacturers. Another key element of a good HPWH design is the collaboration between all parties involved in the project – the manufacturers, the project engineer, and the building owner and maintenance staff. This suggestion was echoed by Evan and Brian both.

Sizing HPWHs for Commercial Buildings

Commercial buildings present a somewhat harder challenge to design HPWH systems because there is less known about how water is used within them. For multifamily buildings, there have been quite a few studies on their hot water use, so you can better predict the water use patterns. In Evan's words this means that "your sizing can be a lot more well-tuned in multifamily buildings, you can hone in exactly how much storage you'll need for peak usage rates, as well as how much recovery you need to recharge your storage tanks for the next peak usage event." The solution to this, that engineers typically apply, is to size conservatively. One method is to consider the worst case peak hour and then look at how much storage and heat pump recovery you need to satisfy this for three hours, which is a relatively conservative approach.

*"For com buildings we don't have as much data, so depending on the building and occupancy type, your usage profiles can be totally different. People are more likely to size off of the peak hour, according to ASHRAE, that are used to size boilers, that gives you a really high recovery rate, but with the proper amount of storage, you almost never need that much capacity with a heat pump. There are a lot more unknowns around commercial buildings and finding that sweet spot between storage and heat recovery." – **Evan Green**, Ecotope*

AO Smith (a leading HPWH manufacturer) has developed a tool they named Pro-Size to size a HPWH for commercial buildings. You start by choosing your building type (hotel/motel, school, office, restaurant, car wash, laundry, etc.). Then you enter in a metric that describes the hot water use of the building - for example in a restaurant its meals served per day, number of sinks, and other fixtures, and for and office it's the number of occupants, bathrooms, water fountains, etc.

Use AO Smith's **Pro-Size** tool to help design heat pump water heating system for your commercial project: *http://www.hotwatersizing.com/Application.aspx*

Looking at a restaurant example in more detail, Figure 17 shows the inputs for the Pro-Size calculator. The result of these inputs is the design suggestion to use one AHPA-125 Air Source HPWH, that will meet the demand down to 45F ambient air temperature, and to use storage of 500 gallons at 140F (example of AO Smith's products would be one TJVT-500A, and two TJV-250A tanks) (Figure 16).

Figure 16: AO Smith AHPA-125 air source heat pump and two TJV-250A hot water storage tank.

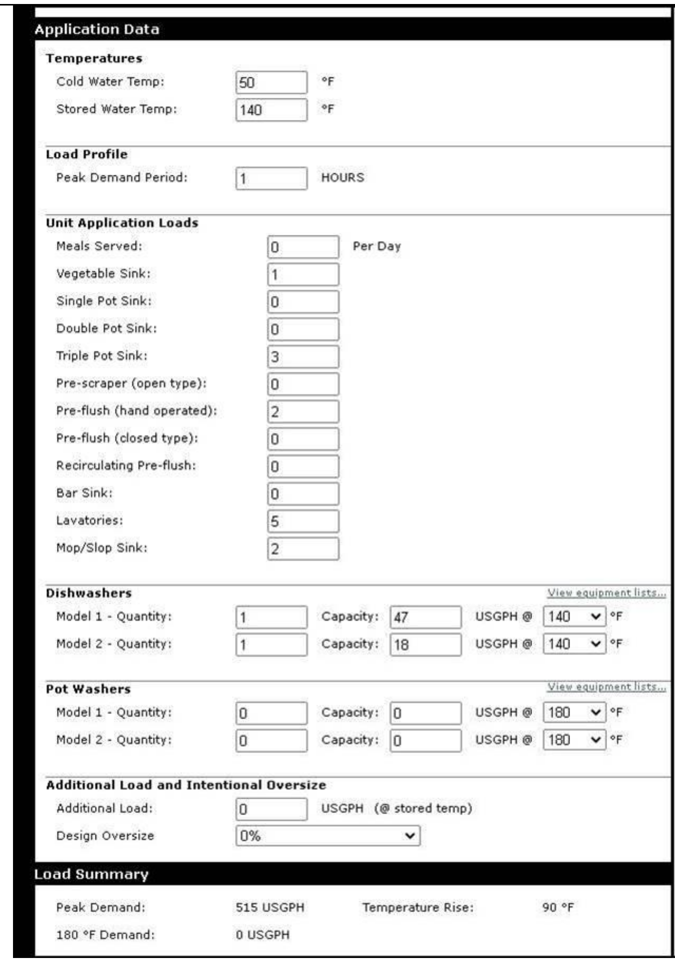


Figure 17: The inputs for AO Smith's Pro-Size heat pump water heater sizing tool for a restaurant.

In smaller commercial buildings where there isn't a lot of water consumption you can use residential type water heaters, AO Smith has a water heater that is integrated (the heat pump is connected to the storage tank), that has 119 gallons of storage that is bigger than residential sized tanks. In addition, where you may have even less hot water use, the use of under sink, tankless or mini tank water heaters can be used, for example in an office bathroom. Another added benefit of using HPWH's is that they can actually cool the space that they are located in, so for a smaller kitchen example, a residential type water heater or the AO Smith water heater mentioned above can actually cool the room it's located it.

Case Study: Arthur Erickson Place, Vancouver BC[51]

The Arthur Erickson Place is a 26-story large office tower in downtown Vancouver, Canada, built in 1968 and retrofitted in 2019. The building is LEED platinum certified and retrofitted its gas-fired domestic hot water boiler with a CO2 based SANCO2 heat pump water heater system, and won an international Innovation in Sustainability competition hosted by one of its building owners, Kingsett Capital in 2020. After the success of the domestic hot water conversion, Colliers (the property management company) and SES Consulting (the lead mechanical consultant) are now working on a zero-carbon retrofit plan for the rest of the building. Read the full case study online at ZEBx's website.

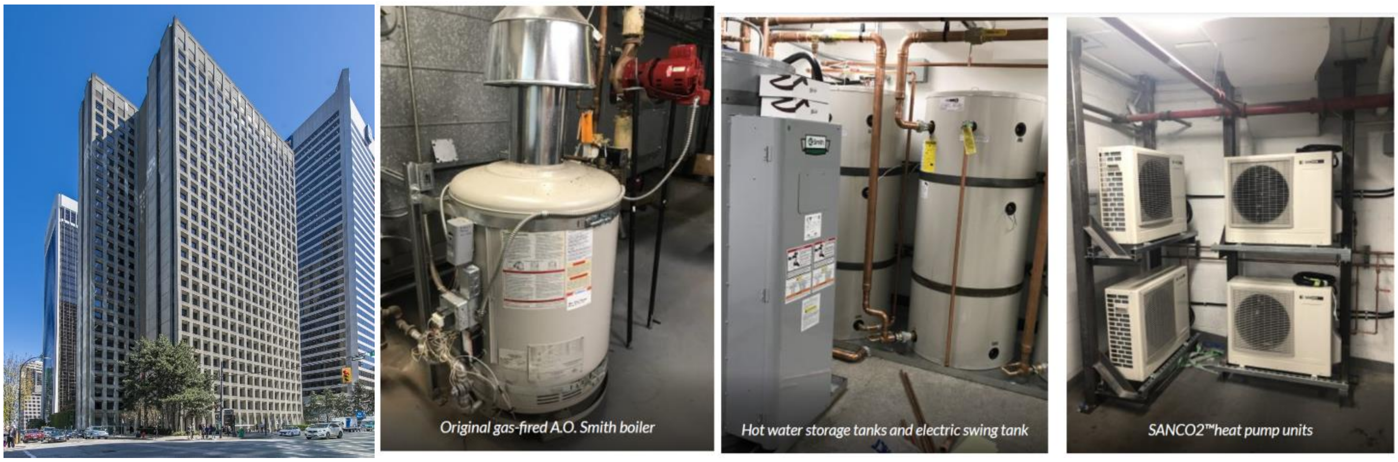


Figure 18: Arthur Erickson Place (left)[52], the original gas-fired hot water boiler (center left), and the electrified heat pump water heater plant storage tanks (center right) and CO2 heat pumps (right).

Additional Case Studies by Small Planet Supply

(Note this was before the development of their skid system)

Walter Gage Housing, University of British Columbia
Vancouver BC; 50 unit Apartment, Boiler Replacement, ~2,000 gallons/day usage, (6) SanCO2 heat pumps; new storage and swing tanks. Image[53]

Northwest School
Seattle, WA; 27 unit Dormitory; Boiler replacement; ~1,500 gal/day usage, (4) SanCO2 heat pumps, (1) Existing 200 gal tank re-used, new 83 gallon swing tank. Image[54]

Case Study: (Multifamily) Bayview Tower, Seattle, WA

Bayview Tower in Seattle Washington, originally built in 1979 and with 100 low-income public housing units, is serving as a demonstration project of the Origin heat pump water heater system that was designed by Ecotope and assembled on a skid by Steffes. The Origin system is a large-volume packaged heat pump water heater system that contains a Mitsubishi CO2 heat pump, storage tank, swing tank, pumps, valves, and controls, everything you need for a plug-in-play water heating solution, and varies in its components based on the building it's assembled for. This new water heater design approach standardizes and simplifies heat pump water heating installations, reducing costs and commissioning errors. The original electric resistance water heating system at Bayview Towers was kept in place as back up to the Origin system. For this building, the primary storage is within the Origin skid, and the existing storage tank is being used as the swing tank. The system's performance will be studied for a year, it is expected to reduce the energy use compared to a conventional system by 59%. Read more about this case study on the Advanced Water Heating Initiative's website.

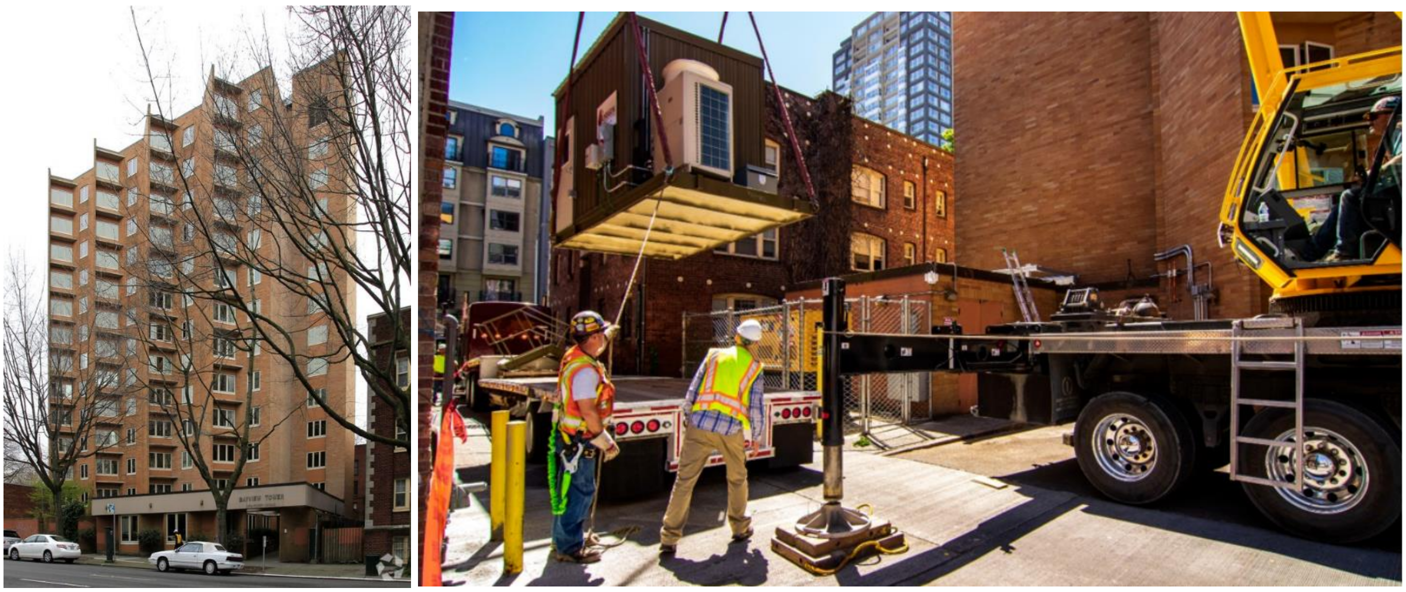


Figure 19: Bayview Tower in Seattle (left)[55] and the Origin heat pump water heater skid system being installed (right)[56].

Case Study: (Multifamily) Elizabeth James House, Seattle, WA

Another case study by Ecotope is the Elizabeth James House in Seattle, Washington which is a four story, 60 unit low-income senior apartment building built in 1968.[59] This project had a central plan of four ECO2 heat pumps, with three existing 120 gallon tanks in a series swing configuration. In addition, the system kept the three electric water heaters, and a 175 gallon swing tank was installed.

Figure 20: Images of the heat pumps[57] at Elizabeth James and the building itself[58]

Additional Case Studies by Colmac[60]

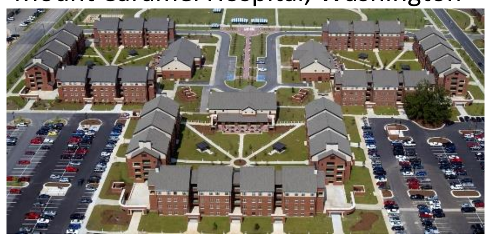
Colmac has been a leading company in the implementation of heat pump water heaters in commercial buildings. Over the years, Colmac had led many installations of their systems in commercial spaces, with a majority being hospitals, clinics, schools, and hotels.


Clark Regional Medical Center, Kentucky

Mount Caramel Hospital, Washington


Berea College, Kentucky


Franklin Monroe School, Ohio


Fort Bragg, North Carolina

Forrest Road School, Illinois


Maluhai Hospital, Hawaii

Pikeville Medical Center, Kentucky


VA Hospital, Kentucky

Seeing this potential, Colmac has also installed a number of their systems in various hotels across the country, but specifically in Hawaii where temperatures are favorable for heat pump water heaters and electricity is the main heating fuel source since access to gas is limited on Hawaii's Islands.


Alohilani Resort Waikiki


Park Shore Hotel


Scenic Towers


Maile Towers

Kitchens in Commercial Buildings

Celebrity Chefs Talking About Their All-Electric Kitchen Retrofits

"**Technology becomes a very powerful, creative tool for us**. It gives us more ways to manipulate the food in unexpected and new ways. It just becomes a creative outlet for us."[61]

-3 Michelin Star awarded Chef Grant Achatz, co-Owner of Alinea in Chicago, USA. Also awarded Best Restaurant in the United States in 2006 by Gourmet Magazine.

"I never thought after 20 years I'd be standing in a kitchen like this…**It's absolutely amazing**."[62]

-3 Michelin Star awarded Chef Heston Blumenthal, owner of The Fat Duck, in his all-electric kitchen near London, England. Also awarded Best Restaurant in the World in 2012 by Restaurant Magazine.

"**I designed the kitchen myself**. It's a gastronomic theater. It's very open, so we can meet the guests and they can see that we enjoy our work."[63]

-3 Michelin Star awarded Chef Rasmus Kofoed, co-Owner of Geranium in Copenhagen, Denmark. Also awarded the Bocuse d'Or in 2010.

"We made the switch to induction as we wanted to make our chefs' lives easier and keep a low turnover of staff. **Our chefs experience far fewer burns using induction**, and **cleaning is easier too**. The induction unit, in particular, has allowed us to serve guests at a significantly faster rate, which is especially useful in the West End with the high number of pre-theatre diners. Overall, the new induction technology has helped to simplify the job."[64]

-Head Chef Alex Povall of Oystermen Seafood Bar & Kitchen, London, England. Awarded Best Restaurant in London in 2019 by both the London Lifestyle Awards and The Observer Food Monthly Magazine.

Electric Kitchen Benefits for Pizzerias, Taco Shops, Soup Kitchens, Burger Joints, Sandwich Stores, School Cafeterias, Gas Stations and Corner Markets

"This equipment is very valuable where you cannot penetrate the walls or ceiling to put a whole new ventilation system in, or you just don't have the space any more." -Andre Saldivar, Senior Engineer at the Foodservice Technology Center of SoCal Edison.

A challenge for entrepreneurs opening up a new restaurant in an existing building is meeting legal requirements for ventilating out the gas combustion pollution. But up to two pieces of electric kitchen equipment from the following list do not require any ventilation system, and many of them are multi-purpose so they can support an entire new menu (see McDonalds' breakfast menu case study below).

- **Rapid cook ovens** (e.g. bar food, pizza, cookies, pot pies, Subway sandwiches, etc.)
- **Conveyors** for steaks, burgers, bagels and more
- **Panini/clam shell grills** for sandwiches, tortillas, rolls, etc.
- **Coffee roasters**
- **Rice cookers**
- **Bagel toasters**
- **Rotisseries**
- **Hot dog and corn cob warmers**
- **Hot plates and countertop induction cookers**
- **Convection ovens** (12 kW or less), Portable ovens (cook-and-hold, infrared and microwave ovens)
- **Popcorn poppers**
- **Rethermalizers** (max temp of 250F)

Restaurants like McDonalds have found they can diversify their menu by adding **compact ventless combination ovens** to their existing kitchens, allowing them to expand their offerings without expanding the kitchen. In 2018 the Director of Operations of eight McDonalds in West Virginia, Randy Westfall, celebrated the new combination ovens in a post-retrofit article on his effort to create a "McDonalds of the Future" in the Times West Virginian: **"We can cook our eggs, bacon, chicken, dessert items — pies, biscuits, things like that."**[65]

Andrew Cherng (Masters in Mathematics) and Dr. Peggy Cherng (PhD of Electrical Engineering) met in Kansas in the 1960s during their undergraduate studies, and in 1982 they cofounded their first Panda Express in Pasadena, CA. Their mutual love of technology led them to innovate as they grew to more than 2000 restaurants[66], including most recently the adoption of **induction warming pans** beneath the serving dishes to eliminate the risk of steam burns to employees, improve food quality, reduce cleaning labor, lower utility bills, and eliminate the water use and plumbing needs of non-induction warming pans.[67]

Hiroaki Aoki started the first Benihana Steak House in New York City in 1964, and it has grown to 116 restaurants. Jokes, juggling knives, flipping shrimp into diners' mouths and slicing ingredients in the air are all part of a performance style of cooking "teppanyaki," Japanese/American steak meals ("yaki") prepared on a "teppan" (steel grill), first innovated in Tokyo in 1945 for feeding post-war American soldiers and brought to the U.S. by a 25 year old Hiroaki Aoki and his father.[68] The Beatles and Mohammad Ali helped make the restaurant famous, and recently it is has earned a new distinction, converting the gas teppan grills to **electric resistance and induction grills**, which can cook meats faster, hotter and more efficiently than gas teppan grills, while reducing the risk of uncontrolled fires—their famous onion ring volcano (see picture) does not need to be even more dangerous!

All-Electric Retrofitted Kitchens in New York City

New York State is home to many fine dining establishments that take advantage of the greater ease of using electric cooking equipment when retrofitting a commercial space into a restaurant. From the traditional griddles at Wallflower to the induction woks at SOLA, from induction heated Mongolian hot pots to the electric deep fat fryers at Rucola, examples abound around New York City of restaurants that have retrofitted commercial spaces with electric kitchens produce more food, at faster speeds, with greater controllability and less air conditioning than gas-burning commercial kitchens. The Big Apple is moving fast to electrify, with former Mayor de Blasio committing to retrofitting all buildings, including commercial kitchens, to carbon neutrality by 2030[69].

Case Study: How Did Stanford University Electrify a Dormitory Kitchen?

Murray House, a private dormitory at Stanford University that includes a diverse meal plan for students from around the world, all of which is cooked in a 2021 retrofitted electric commercial kitchen.

The replaced Murray House gas-burning kitchen equipment.

Since World War II Stanford University, and the small cities that surround it, have became a globally famous center of technological innovation known as “Silicon Valley,” home to firms that, like Stanford, have already embraced all-electric construction in their cafeterias, like LinkedIn, Google and Adobe.

Stanford University has been rapidly retrofitting its campus to all-electric, and has a new academic program called the Building Decarbonization Learning Accelerator. In addition to Stanford’s noteworthy whole-campus heat pump system, electric bus fleet, and 82% offset solar array, in 2021 the Murray House private dormitory recently retrofitted its gas-burning commercial kitchen with electric equivalents--a commercial electric fryer, two electric griddles with convection ovens, and an induction range.[70] EHDD, an industry-leading decarbonization-focused architecture firm, led the redesign.

Retrofitting Kitchens on a Tight Budget: 120V plug-in kitchen equipment can allow entrepreneurs to open restaurants in new storefronts with minimum retrofits, using 120V induction cooktops, panini press grills, waffle makers, ovens and coffee makers to accomplish everything with the existing wiring and no new gas. Electric kitchen equipment has all of the product options available in gas, as well as many more, particularly combination equipment that allows chefs to free up space and lower the overall equipment budget. See the extensive Product Guides at the end of this document for more products.

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

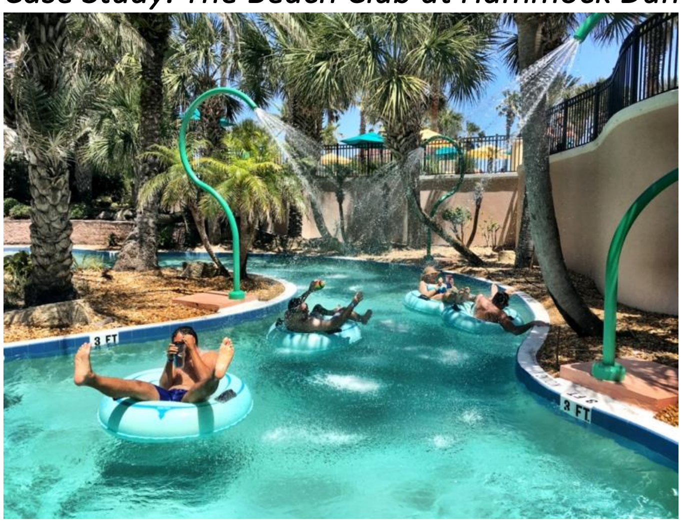
Retrofitting Heat Pumps into Commercial Pools

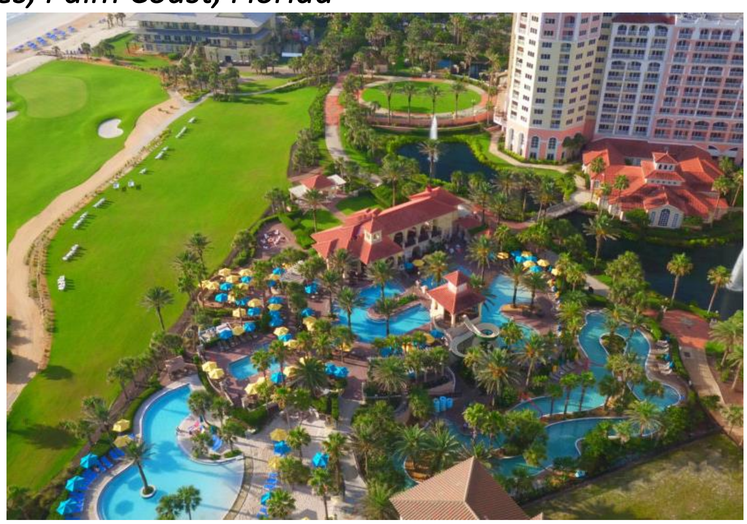
Commercial swimming pools at hotels, condos and public parks are a community treasure worldwide, and they are increasingly being heated to extend the swimming season and provide warmer swimming water. However, heating such large volumes of water, particularly in the open air, can be very expensive, which has led to heat pumps growing in market share—they use 1/4th to 1/20th as much energy as a gas-burning pool heater, and make outdoor hot tubs and swimming pools more affordable.

How to Size the Heating Capacity of a Pool Heat Pump: Heat pump pool heaters are sized differently than gas pool heaters, running continuously rather than off-and-on. To right-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.[71] Most air source heat pumps are sized for up to 35,000 gallons,[72] and set up in parallel for larger pools with controllers such as Hayward's "Omnilogic."[73] However, there are very large air source heat pumps just for pools (e.g. AquaCal's "Big Bopper"), and pools may be heated as part of a campus-wide heating system (e.g. Stanford's campus) using industrial-scale heat pumps.

How Heat Pumps Lower Pool Heating Costs: Heat pump pool heaters save pool owners on their utility bills compared to gas pool heaters. This is because heat pumps are dramatically more efficient, collecting 3 to 13 units of heat from the environment (air, ground or water) for every 1 unit of electricity used,[74] while gas pool heaters collect only 0.8 to 0.9 units of heat for every 1 unit of gas energy that is burned. AquaCal provides an excellent heat pump capacity sizing estimator that also performs cost-of-use estimates: https://www.aquacal.com/sizing-and-savings-calculator/

Case Study: The Beach Club at Hammock Dunes, Palm Coast, Florida





The Beach Club at Hammock Dunes, Palm Coast, Florida replaced propane boilers with the largest commercial Air Source Heat Pump available in the U.S., the "Big Bopper" by Aquacal, as well as a ground source heat pump for the hot tubs. Bob Greenberg, the President of the Homeowners Association there, initiated the retrofit because, "We were burning propane gas, and the prices were going up to a ridiculous amount, and eating up lots of dollars in our budget. We have two years of records, and we've cut our heating costs in half." Erik Eskeland, the installer at Four Season Pools, noted "They're able to swim year-round, and it has paid for itself in less than a year."[75]

Case Study: Hot Pools at Tamarack Club Slope Side Hotel, Ellicottville, New York

Skiing right up to a 103F adults-only hot tub and heated outdoor saltwater swimming pool are among the many luxuries of the Tamarack Club Slope Side Hotel. In the summer the residents and vacationers can enjoy golfing followed by a swim in one of the three heated pools, adults-only hot tub at 103F and a youth hot tub at 99F.

The 2010 retrofit to the pools converted from propane to *air source* heat pumps for the pools, with the hot tubs drawing heat from the single swimming pool kept hot in the winter with a *water source* heat pump. This allows the air source heat pump to do the hardest work, gathering heat from 0F air to raise it to 85F, and the water source heat pump only has to concentrate the heat up to 85F to 103F. Among engineers, using two types of heat pumps to raise temperatures is called a "cascading system."

According to Joe, the satisfied Maintenance Supervisor at The Tamarack Club, "Maintenance is way down, I mean, less than half what we used to do." [76]

Case Study: Kihei Aquatic Center Pools, Kihei, Maui Island, Hawaii

The Kihei Aquatic Center was built in 1998, but by 2005 the gas heating system was failing to keep up heating loads. Heat pumps now serve the pools, including an Olympic sized swimming pool, an an 8 lane competition pool, a springboard pool and a Keiki (Children's) pool with a fountain. This beloved community resource on the west side of Maui was the host site for the 2005 and 2007 Jr. Pan Pacific Swimming Championships.

Case Study: Hallenbad City Public Pool, Zurich, Switzerland

The first public pool in the world to use a heat pump was built in 1941 in Hallenbad City, a neighborhood of Zurich, Switzerland. The water source heat pump draws heat from a nearby medieval moat built in 1300 to protect the city. During WWII fossil fuels were scares and insecure, so Switzerland built hydroelectric dams and paired the secure electricity source with heat pumps for public buildings—heating city halls and public pools. The Hallenbad City public pool is still in use, and over the last 80 years the (moat)water source heat pumps has been replaced in 1980, 1996 and 2013.[77]

Case Study: The Jekyll Island Club Pool, Jekyll Island, Georgia

In 1886, a group of American society's wealthiest families - the Astors, Rockefellers, Vanderbilts, Goulds and Morgans, representing 1/6th of the world's wealth– bought an abandoned cotton plantation on a remote Georgia island, and developed the Jekyll Island Club. At the time, Munsey's Magazine called it "the richest, the most exclusive, the most inaccessible club in the world." When telephones were invented, the island was one of first five places in North America with a transcontinental telephone, which allowed residents like the CEO of AT&T to directly call President Woodrow Wilson.

On the island the families built a shared residence, one of the nation's first condominiums, on the scale of a royal palace, with the island transformed into a private winter hunting retreat. Over the years they added a marina, an 18 hole golf course where the USGA first tested steel (rather than hickory) golf clubs, croquet lawns, tennis courts and a large swimming pool, with electricity and wood providing all the energy to the island. After WWII the families sold the estate to the State of Georgia and in 1952 lowered the drawbridge to the island to let the public in.[78] The swimming pool is now heated by an air source heat pump, and the palace has become a high-end, historical landmark hotel within a Georgia State Park.

Power Savings Opportunities in Commercial Buildings

Electric devices have grown more efficient and more controllable since our buildings were initially built. The amount of wattage needed for lighting is dramatically lessoned by efficient LEDs replacing the common fluorescent lighting of old and especially replacing incandescent and halogen lighting. The amount of wattage needed for an efficient rooftop heat pump vs. the prior gas-pack air conditioner and gas furnace may also be reduced. Even selecting lower wattage, higher storage volume, water heaters produces panel watt savings. There is also a lot of freed up wattage as we switch to modern controls like daylighting controls, and load shifting controls on HVAC and water heating as well as circuit sharing controls.

Ways to reduce power in commercial building retrofits:

- Changing to LEDs from older lighting technology
- Sharing multiple EVs on circuit
- More efficient heat pumps
- Lower wattage heat pump water heaters and more storage

These watt savings accumulate naturally in the electric panel and present the opportunity to be deployed into added carbon savings by being deployed as fleet vehicle charging in the stationary hours (e.g. night) and as daytime EV charging for staff and visitors. Modern EV charging controllers can also increase delivery to the vehicles in real time whenever there is room on the transformer or extra energy available from on-site solar.

The best way to look at it is that the onsite transformer and electric service line and main electric panel are important assets in the pursuit of electrifying everything (economy-wide). Those assets should not languish under-utilized especially during the daytime hours when our grids will be awash with solar electric generation. We should design-in the opportunities to not only make our buildings fully electric but also to deliver spare grid capacity via daytime EV charging into the batteries of vehicles. That way those same vehicles do not need to get that amount of charge overnight when our future solar powered grids will be drawing from storage on the margin.

Following the watt diet principles to free up watts and then delivering them to EVs that have on-board final-destination storage batteries is the smart way for society to meet its needs with minimum costs (minimum total batteries).

Looked at holistically, watt-dieting (and on-site solar deployment when feasible) freeing up power for the maximum number of load managed EV charging ports supportable by the property transformer is the next frontier in decarbonized commercial properties.

Property assets to maximize:

- Building's ability to watt diet and free up power, even while being fully electrified
- Building natural thermal storage and water heating thermal storage ability to shape load
- Onsite batteries' ability to shape load
- Transformer's ability to provide daytime grid power
- Solar's ability to provide daytime power
- Automated load control of multiple EV charging port's ability to variably charge many EVs with available power.

Appendix A: HVAC Definitions

The definitions listed below come from the California Commercial Saturation Survey[79] and are referenced in the HVAC section above.

Package Single Zone (PSZ)

A package single zone system is a unitary piece of equipment; all of the components are contained in a single box including the compressor, condenser, expansion valve and evaporator. PSZs are outdoor units typically mounted on the roof, with ductwork that provides conditioned air to the occupied space. These units typically have gas heating, but can also be heat pumps or, very rarely, electric resistance heating.

Package Multi Zone (PMZ) and Package VAV (PVAV)

Package multi zone and package variable air volume units are similar to a PSZ with the exception that they can condition multiple spaces. These systems will have multiple thermostats to control each zone. These units will typically be much larger than PSZ units.

A PMZ is a constant-volume, single speed fan system, whereas a PVAV uses a variable-air flow fan system which includes VAV terminal boxes in the ceiling to control the volume of air entering the space.

multizone, much larger than single zone, and VAV box

Split System Single Zone (SSZ)

A split-system single zone system consists of an outdoor unit and an indoor unit. The outdoor unit contains the condenser and compressor elements of the system while the indoor unit will contain the fan, filter, heating section, cooling coil and expansion valve. The indoor unit distributes conditioned air to the space via ductwork. Split systems can provide both heating and cooling. Many of these smaller systems are very similar to residential systems. For other larger systems, the outdoor units will be mounted on the roof or ground, and the indoor units will be located in the ceiling.

outdoor / indoor

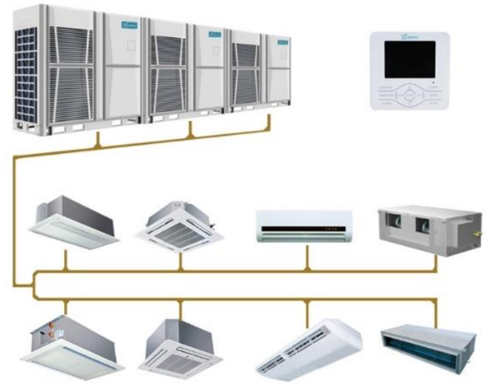
Packaged terminal unit (PTU) – Single Zone

A package terminal unit is a unitary, window or through-the-wall type air conditioning unit, and they are non-ducted. These units are typically either cooling-only or heat pumps. They are commonly found in small and/or portable offices, and apartment buildings or motels where they only need to condition a relatively small, single space

Ductless, Mini-Split Unit (MINI) – Single Zone or Multiple Zones

A ductless mini split system is similar to a SSZ in that it will have an indoor and outdoor unit, but unlike the SSZ a MINI is a non-ducted system. The indoor unit is located directly in the space it is conditioning. They are often used in server rooms to provide dedicated cooling, or other spaces that are isolated from the primary HVAC system. They are also being used more often in place of a PTU. Also like the SSZ, minimum equipment efficiencies for this equipment are specified on a SEER basis.

single family (left) and commercial application (right)

Variable Refrigerant Flow (VRF) – Multiple Zones *Similar to the MINI system, but larger in capacity. VRF systems are also similar to SSZ systems, but have with more sophisticated controls and variable amount of refrigerant and are typically non ducted.*	
Unit Ventilator / Unit Heater (UV) – Single Zone *A unit ventilator is a unit that only provides heating or ventilation. Unit heaters are typically located directly in the space and therefore have no duct work. These units can rest on the ground or be suspended from the ceiling. While the majority of UVs use a gas or hot water heating source, they can also use steam or electricity.*	
Built-Up Systems – Single Zone or Multizone ***<u>Serving one zone per unit:</u>*** *A **built-up single zone system** is a custom, ducted system comprised of individual components including, but not limited to, compressors, chillers, boilers, fan coils, air handlers, and cooling towers. The hot or cold air will be distributed to the space via an air handler or fan coil unit, and each one serves a single thermal zone.* ***<u>Serving multiple zones per unit:</u>*** ***A built up multi zone system** is a custom designed system comprised of individual components such as chillers, boilers, fan coils, air handlers, and cooling towers that serves multiple thermal zones. A built-up multi zone system that also incorporates variable air volume air delivery instead of constant-volume is a built-up VAV system.*	 (boiler / air cooled chiller / air handler)  VAV box at zone
Baseboard Heater / Radiant Heater (BB) – Single Zone *Baseboard-radiant heaters use electrical resistance, hot water or gas as the heat source, and as the name implies, they heat the space **radiantly**. Radiant systems can be configured as baseboards, radiators, or embedded in or attached to floors, walls, or ceilings. These units are often called "zonal" heating systems because they are located directly in the space being heated, and they do not use ducts or fans.*	
Portable Space Heater (PH) – Single Zone *Portable space heaters are electric resistance heaters that are plugged in and typically used in the corner of an office or a workstation in a warehouse. These units can be easily moved around from one area to another. Although these could be considered miscellaneous plug loads, they have been grouped into HVAC for the purposes of the CSS study*	

Portable Spot Cooler (SC) – Single Zone

Portable spot coolers are compact, air-conditioners designed for spot-cooling, emergency cooling, and after hour cooling. These units are typically like a PTU to which flexible ducts are attached on both the cooled air and heat rejection ends of the units, which allow the cooled air to be focused on a specific spot (such as an overheating server) or interior space that is isolated from the primary HVAC system. The heat rejection duct can be similarly directed to the outdoors or to another adjacent space. Although these units are intended primarily for use as temporary cooling solutions, SCs are sometimes observed in a more permanent installation.

Ground Source Heat Pump (GSHP) – Single Zone or Multiple Zone

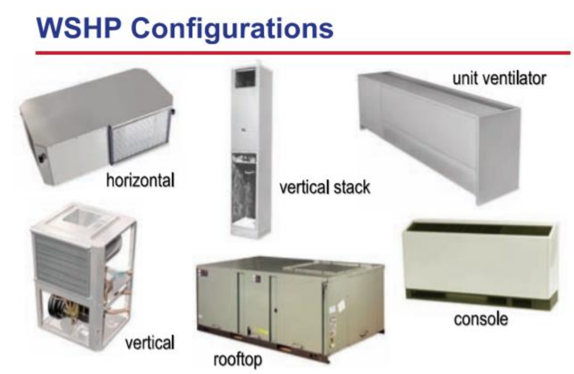
A ground source heat pump uses the earth as a heat source in the winter and a heat sink in the summer. The ground stays a constant temperature and therefore can be relied upon to keep the space a constant temperature. The hot or cold air is then distributed via ducting.

Wood / Pellet Stove (WF)

These wood furnaces are small wood or pellet burning space heaters. They are used to heat a single room and typically have an exhaust fan leading out of the space.

Water Loop Heat Pump (WLHP) – Multiple Zones

*A water loop heat pump system consists of multiple packaged, water-cooled heat pumps that are tied to a water-loop that runs throughout the building. The water loop is maintained at a temperature between 60°F and 90°F. A **cooling tower** is used when the water loop temperature is above 90°F where as a backup **boiler** is used when the water loop temperature falls below 60°F.*



2 Pipe Fan Coil (2PFC) and 4 Pipe Fan Coil (4PFC) – Multiple Zones

Two-pipe and four-pipe fan coil systems provide heating and cooling to a space via a chilled/hot water loop circulated through fan coil units, each of which serves a single thermal zone.

A 2PFC has only one supply and one return line (2 pipes) and as such can only provide either heating or cooling, but not both at the same time. A four pipe fan coil (4PFC) has four lines – two dedicated for chilled water, and two for hot water – so a 4PFC system can provide simultaneous heating and cooling.

(Fan coil units)

All-Electric Product Guides

The following product guides provide an overview of electric products on the market as guidance to electrify all the end uses in ***single-family homes to commercial buildings***. This guide includes the basics – space heating and cooling and domestic hot water – as well as cooking, laundry drying, and accessory end uses like electric fireplaces, electric cars, electric car chargers, landscaping, and pool heating. A snapshot of technical specifications as well as the retail price of each product is provided in the tables below. It is suggested to find the most up to date specifications online, exact numbers may change as newer product versions are available and costs may vary.

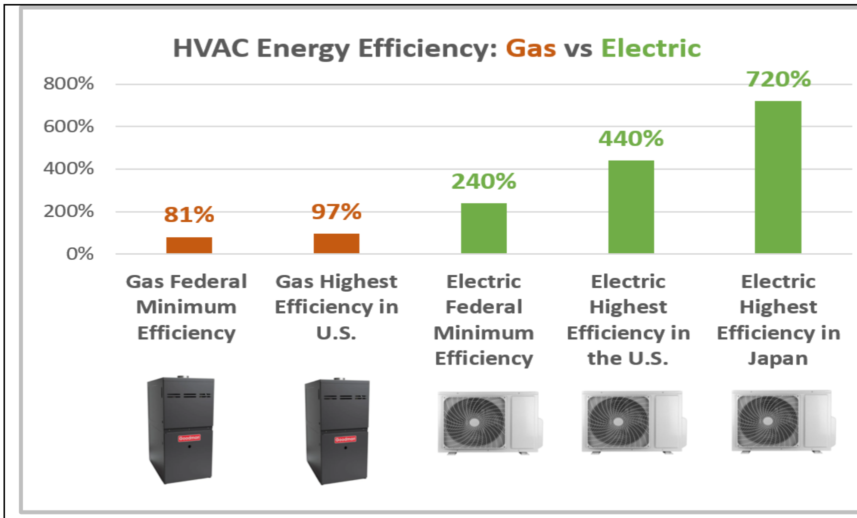


Figure 21: Air source heat pumps collect more energy from the air than they use to gather it. (Image by Redwood Energy).

Heat pumps are a key solution to meeting our largest energy demands in buildings—space heating and water heating. Heat pumps go by many names depending on their applications like "refrigerators," "air conditioners," "air source heat pumps," and "reverse chillers." The history of chemical refrigeration dates to the 1550's when saltpeter baths were first used to chill wine. Ice manufacturing was a booming business by the late 1700's, and the first true "refrigerator" 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 compressor in 1902 also in Brooklyn, NY. Residential refrigerators were common by the 1920's, and reversible air conditioners (aka "heat pumps") came on the market in the 1950's. Today, heat pumps are very efficient and are typically at least double to triple the efficiency of their gas counterparts. In Eurasia where heat pumps have been more widely adopted and manufactured, some heat pumps are up to 720% efficient (Figure 21).

Heat pumps can draw their energy from three main sources - the air, the ground and water - this energy is then moved into either air, water, or refrigerants which are cycled through the building to meet heating and cooling needs. The most common and flexible heat pumps are "air source", like that in your refrigerator or your air conditioner. "Ground source" and "water source" are a little less common and are usually used on larger scale and use the soil or bodies of water as heat sources. "Air to water" heat pump refers to a two-stage process, where there is a central air source heat pump that chills or heats water, then that water circulates through the building instead of air.


Figure 22: Fujitsu heat pump in the snow.[80]

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)[81], where early models were limited to warmer climates (Figure 22) . 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. **Cold climate products are indicated by a blue highlighted cell and bold text in the tables below.**

Domestic Hot Water

The following section provides electric alternatives to gas water heaters for larger, multi-family and commercial applications. Heat pump water heaters deliver hot water at high efficiencies and typically come with electric resistance back up for peak loads. See more air to water heat pumps in the HVAC section below.

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

*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***

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 BTUh) 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 vs. 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[82] can deliver water temperatures as high as 180 Fahrenheit, 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 water allows them to be a direct replacement for gas boilers in high temperature applications like hospitals, high rise apartments, universities, and more.

	Colmac **CxA** 	***Colmac*** ***CxV*** 	**Mayekawa** **Unimo "Eco Cute"** HE-HWA-2HTC 	**Aermec** **ANK** (030,045,050) 
Description	Air source heat pump water heater	Air source heat pump water heater	Water source heat pump water heater	Multipurpose heat pump - single unit
Voltage (V)	230/460	230/220	400	208/230
Dimension (ft)	3W	-	4.1W x 6.2L x 6.8H	4.2H x 4.8W x 1.5D
Ref. Type	R134a	R134a	R744 (CO2)	R134a
Ambient Temp. Range (F)	10 (low)	**-4 – 120** **(cold climate)**	14 - 110	-4 - 113
Max Outlet Water Temp (F)	160°F	140°F	194°F	113°F
Power (W)	-	4,900 – 6,300	-	2,810 – 4,520
Amps (A)	21.1 – 86.5	36.8	120	45
Heating Cap. (BTUh)	137,500 – 419,400	31,200 – 77,900	200,600 – 284,200	37,670 – 57,598
Cooling Cap. (BTUh)	109,700 – 334,100	17,300 – 60,700	-	30,120 – 48,240
Heating (COP)	4.0 - 4.2	1.8 – 3.7	3.40 – 3.89	3. 1 – 4.4
Cooling (COP)	3.2 – 3.5	1.0 – 2.9	2.62 – 3.28	-

	Lochinvar AHP090 	**Nyle** (C25A-CSA250A) 	**Nyle** E360 	**AO Smith** CHP-120 
Description	Air Source Heat Pump water heater	Air source heat pump water heater	Split heat pump water heater	Heat pump water heater w/ 112-gal tank
Voltage (V)	208/230	208/230	208/230 440/480 575	208/240
Dimension (ft)	5.8'L x 2.73'W x 5.85'H	7L x 4.6W x 5.6H	3.33L x 6W x 7.43H	5.7H x 1.91W x 3.25D
Ref. Type	134a	134a	513a	134a
Ambient Temp. Range (F)	40 - 120	40 - 120	10 - 120	20 - 110
Max Outlet Water Temp (F)	160°F	160°F	160°F	150°F in hybrid mode 180°F in electric mode
Power (W)	-	-	-	2,350
Amps (A)	39.3	6.2 -23.9	-	67
Heating Cap. (BTUh)	110,725	27,450 – 272,450	360,000	37,977 HP mode 40,945 Electric mode
Cooling Cap. (BTUh)	83,625	21,200 – 218,000	-	-
Heating (COP)	-	4.45 - 5.18	COP up to 4.0	4.2
Cooling (COP)	-	3.88 - 4.20	-	-

Best Practices for Heat Pumps Central Domestic Hot Water Systems[1]

Using heat pumps as a space cooling device date back to the 1920s, and space heating to the 1940s. However, using compressors to heat domestic hot water for cafeterias, apartment complexes, dairies[2] and other large uses has only existed since the 1970s. Additionally, the technology has advanced further in Asia where efficiency is more valued resulting in North American designers to be less familiar with both the products and practice of designing commercial hot water systems using heat pumps. Below is a guide from the engineers at Ecotope of Seattle, the most experienced designers of central domestic hot water heat pumps in North America (25 systems so far).

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 to 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 usage load***. Temperature maintenance 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 recirculating water, to efficiently lift temperatures from 50F to 150F.
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 that found in a wall.
5. ***Design diagnostics at 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 maintenance.
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 23: 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.[1]

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[1] Several Presentation Links from Sean Oram of Ecotope are provided: Heat Pumps 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

[2] 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

Product Highlight- SHARC Energy Heat Pump

SHARC Energy Heat pumps recover heat from wastewater to produce water heating, and space heating and cooling, setting it apart from most heat pumps in the market as it can create a circular flow of heat and energy. For industrial-sized filtration and heat transfer applications (District and campus energy, commercial food production, Hospitals, 350+ unit apartments), the SHARC Series three models provide water heating and cooling as well as space heating. For Medium-sized heat transfer applications (50 - 350-unit apartments, hospitals, community housing, commercial laundry) there is the Piranha Series. The Piranha series utilize grey and black water and is optimized for multi-family residential and light commercial applications. While the three Piranha models focus on providing hot water, the three Piranha HC models allow simultaneous heating and cooling, providing both water heating and space cooling. All SHARC Energy products are designed to be scalable and to make retrofitting as seamless as possible.

	Piranha Series (T5, T10, T15)	**Piranha HC Series (T5, T10, T15)**	**SHARC Series (660, 880,1212)**
Manufacturer and product image			
Description	Hot water production using wastewater heat recovery, heat pump	Space cooling and hot water production using wastewater heat recovery and heat rejection, heat pump	Industrial filtration, heating, and cooling using wastewater
Gallons (Tanks sold separately)	750-2,250 External holding tank, minimum recommended value	750- 2,250 External holding tank minimum recommended value	Wastewater holding tank sized to fit the specific project, assisted by SHARC Energy
Dimensions (in) (LxWxH)	T5/HC: 57x33x70 T10/HC: 66x42x74T15/HC: 85x59x74	T5/HC: 57x33x70 T10/HC: 66x42x74T15/HC: 85x59x74	Varies 660/880/1212 increase in size, heat exchangers are selected for specific projects and will vary in size and length based on flow rate and thermal design conditions
Ref. Type	R-513a	R-513a	
Heating Cap (BTU/h)	60,000-180,00 BTU/h	60,000-180,00 BTU/h	Variability for the SHARC systems based on design flowrates and thermal transfer design values.
Cooling Cap. (BTU/h)	N/A	48,000-144,000 BTU/h	Variability for the SHARC systems based on design flowrates and thermal transfer design values
COP			up to Megawatts of thermal energy transfer for very low kilowatt energy consumption
MOCP (A) size of circuit	Piranha T5: 90 A Piranha T10 208/230 V: 150 A Piranha T10 460 V: 70 A Piranha 15 460 V: 110A	Piranha T5 HC: 90 A Piranha T10 HC 208/230 V: 150 A Piranha T10 HC 460 V:70 A Piranha 15 HC 460 V: 110A	SHARC 660(208V, 460V, 575V): 40A, 20A,20A SHARC 880 (208V, 460V, 575V): 50A,25A,20A SHARC 1212 (208V, 460V,575V): 80A, 35A, 30A
Voltage (V)	208/230-460 V T15 in 208/230 V	208/230-460 V T15 in 208/230 V	208/230 V, 460 V, 575 V

Individual Heat Pump Water Heaters (240V and 120V)

Typical electric water heaters that use electric resistance are not shown due to their inefficiency. 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 24: A Steibel Eltron heat pump water heater installed in a basement in the Northeast.[83]

Figure 25: A Sanden CO2 heat pump water heater compressor working outside in 5°F (-15°C) weather.[84]

Heat Pump Water Heaters on US Market (240V)

Manufacturer and Product Image	**Eco2 Systems**	**Steibel Eltron** Accelera	**Rheem** Prestige Hybrid	**AO Smith** Voltex Hybrid	**Bradford White** AeroTherm
					
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)	38H x 24.5Diam.	60H x 27Diam.	74H x 24Diam.	69H x 27Diam.	71H x 25Diam.
Ref. Type	R744 (CO2)	R134a	R134a	R134a	R134a
Ambient Temp. Range (F)	**-30 – 110 (cold climate)**	42 – 108 / 6 – 42	37 – 145	45 - 109	35 – 120
Power (W)		650 - 1500		4,500	550 – 4,500
Max Amps (A)	13	15	15 – 30	30	30
Heating (BTU/h)	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

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.

Manufacturer and Product Image	**E8** Nyle 	**GE** GeoSpring 	**Rheem** Prestige Hybrid 
Description	Split Heat Pump Water Heater, Refrigerant	Heat Pump Only	Heat Pump Only
Gallons	Tank sold separately 40-120 gal	40, 50	40, 50, 65, 80
Voltage (V)	120 V	120V	120V
Dimension (in)	(L X W X H) 21 ¾ X 21 1/16 X 18 3/8	More Specifications Coming Soon	66H x 23 Diameter
Ref. Type	513 A		R134a
Ambient Temp. Range (F)	38 - 120		45 - 140
Power (W)	900		2,400
Breaker Size (A)	15 A		20A
Heating (BTU/h)	8,000		12,000
Energy Factor	-(2.8)?		3.0
COP	2.9 @ DOE 80.6F, 70-120F water Up to 4.0		
Price ($)	$2,499		

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.[85] At low outdoor air (-15°F) and low inlet water temperatures (Figure below) it can make hot water up to 145 degrees Fahrenheit, 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 efficiency 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 26: The Eco2 heat pump water heater compressor working outside in 5°F (-15°C) weather.[86]

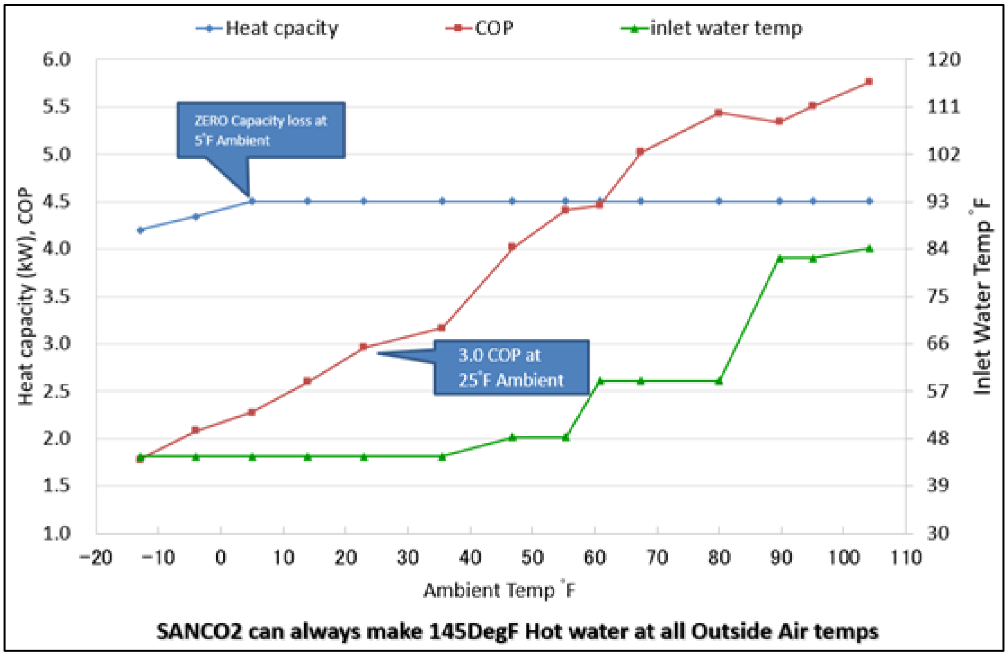


Figure 27: Eco2 heat pump water heater heating capacity, COP, and inlet water temperatures at various ambient air temperatures.[87]

Harvest Pod by Harvest Thermal

Most Homes have two heating systems (air and water), together these systems account for most of your home's carbon footprint. The Harvest Pod technology uses a single heat pump to control both air and water heating, it also chooses when to run the heat pump, to automatically use your utility's cleanest electricity. The unit only provides heating for now, so a separate cooling system is still needed, however the unit can provide outside air ventilation and night cooling.

The water is heated at times when electricity is cheapest and cleanest and stored in the tank for whenever it is needed. This slashes the carbon footprint of your heating and water by 90% and saves between 20% and 40% on heating and hot water costs. The SANCO2 heat pump water heater would be the perfect accompanying hydronic heating system for the Harvest Pod. As the SANCO2 is sold as an individual heat pump water heater, and the Harvest system would require a "single pass" heat pump that is able to efficiently lift temperatures.

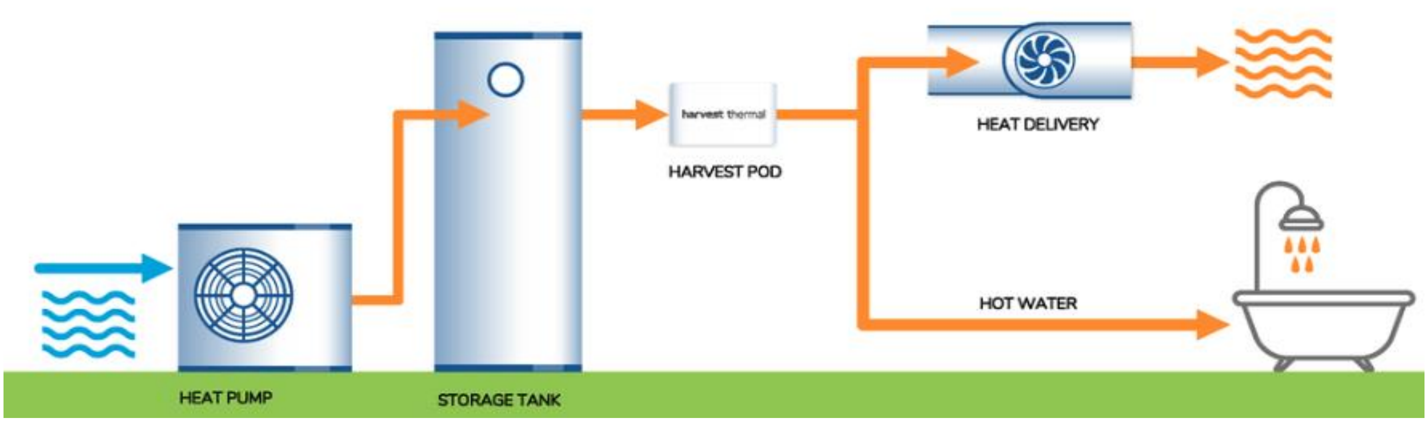


Figure 28: A simple diagram of the Harvest Thermal system.[88]

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 that 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 	**Rheem** EGSP2 – EGSP30 
Description	Hybrid Heat Pump with Resistance	DC Inverter Heat Pump Water Heater	Electric Resistance Tank
Gallons	18.5 (70L)	53 (200L)	2.5 – 50 Gal
Voltage (V)	220 @ 50 Hz	220V @ 50 Hz	120, 208, 240, 277, 480V
Ref. Type	R134A	R410A	Electric Resistance
Ambient Temp. Range (F)	**5 – 68 (cold climate)**	**-13 – 118 (cold climate)**	**Delivered Hot Water: 110-170F**
Power (W)	860 – 1500	5,000	1,500 – 6,000
Max Amps (A)	Pending	20	25A @ 240
Heating (BTU/h)	12,500	27,000	5,000 – 20,000
Heating (COP)	1.36 - 5.34	Pending, Approx. 5.4	>1
Energy Factor	Pending	Pending	-
Price ($)	UL Certification Pending	UL Certification Pending	$400 - $2,000

Three ways to get more hot water – which one is right for you?

The more people in the home, the more hot water you will use. If you have two people in your home you will probably want a 40 gallon water heater, for three people would use 50 gallons, 4 people would use 65 gallons, and 5+ people use 80 gallon tanks.[89] Current (no pun intended) Heat pump water heaters are generally either 30-amp or 15-amp machines based on the Amperage of the electric resistance backup elements they use to supplement the heat pump. The 15-amp products put less power into the water during the course of the first hour test so all else being equal, they would deliver slightly less hot water in the first hour test and thereby have a lower **first hour rating**.

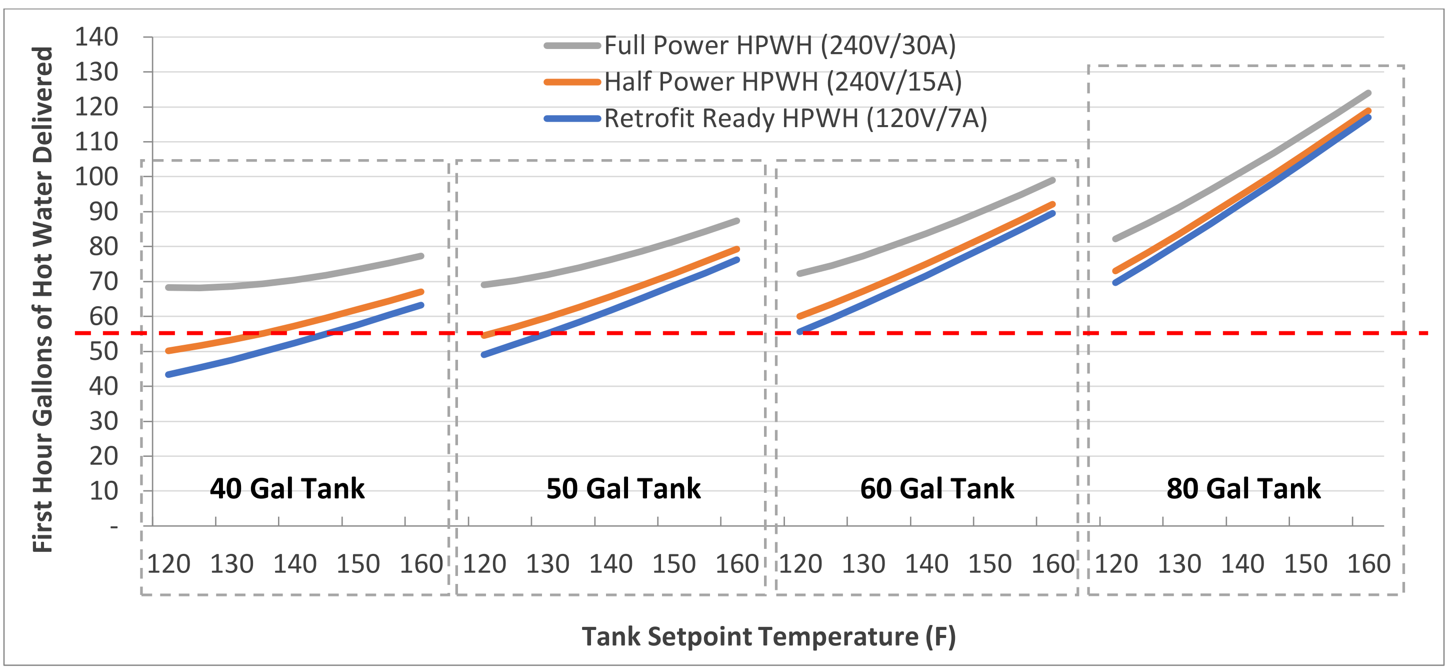
Below is a figure that estimates the hypothetical first hour rating for the various power levels of heat pump water heaters (High Power, Half Power, and 120V Retrofit Ready) and for the size of the tank (40-80 gal). For example, in a three-person home, the first hour rating would be around 55 gallons, so a 120 V "retrofit ready" heat pump water heater or a 240V / 15-amp "half power" heat pump water heater that is 40 gallons would be adequate. Also, it's important to note that the more hot water storage you have, the more hot water you can deliver in the first hour.

Three ways to get more hot water:

1. Set the tank to a higher temperature (and use a mixing valve to avoid scalding if you are setting it above 130F)
2. Select a larger volume tank
3. Select a higher power heat pump water heater that is 30-amps

Interpreting the graph below, there are nine ways to get a 70 gallon first hour rating:

1. A full power 40 gal tank at 130F (no mixing valve needed).
2. A full power 50 gal tank at 120F
3. A half power 50 gal tank at 150F with mixing valve
4. A 120V 50 gal tank at 155F with mixing valve
5. A full power 60 Gal tank at 120F
6. A half power 60 gal tank at 135F
7. A 120V 60 gal tank at 145F with mixing valve
8. A half power 80 gal tank at 120F
9. A 120V 80 gal tank at 122 F



Approximate "first hour rating" (3gpm until the hot water runs out) based on the power of heat pump water heater, tank size and temperature setting.

Heating, Ventilation and Air Conditioning

The following guide gives an overview of heating and cooling electric systems that are used in single-family, multifamily and commercial buildings. They range in size from 9,000 BTUh to 600,000 BTUh 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. **Cold climate products are indicated by a blue highlighted cell and bold text in the tables below.**

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/*

Overview of Single-Family HVAC

Ducted Split	Ducted Mini-Split	Ductless Mini-Split	Window	Portable	Through-wall	Hydronic	Geothermal

What is considered "high efficiency" for space conditioning air-to-air heat pump?

SEER is used to rate air conditioner efficiency, while HSPF is used to rate heating efficiency. Typical efficiencies for a heat pump range from 14 SEER / 8.2 HSPF on the low end for ducted systems up to 38 SEER / 15 HSPF on the high end for ductless systems. If your home is striving for high performance goals, then seek a system above 20 SEER and above 10 HSPF. An important thing to note is that the most efficient furnace is only 97% percent efficient at converting fuel to heat, while the most efficient mini-split heat pump is 410% efficient at heating (HSPF ~ 14).[90] (Note this graphic is for ***residential*** sized HVAC systems)

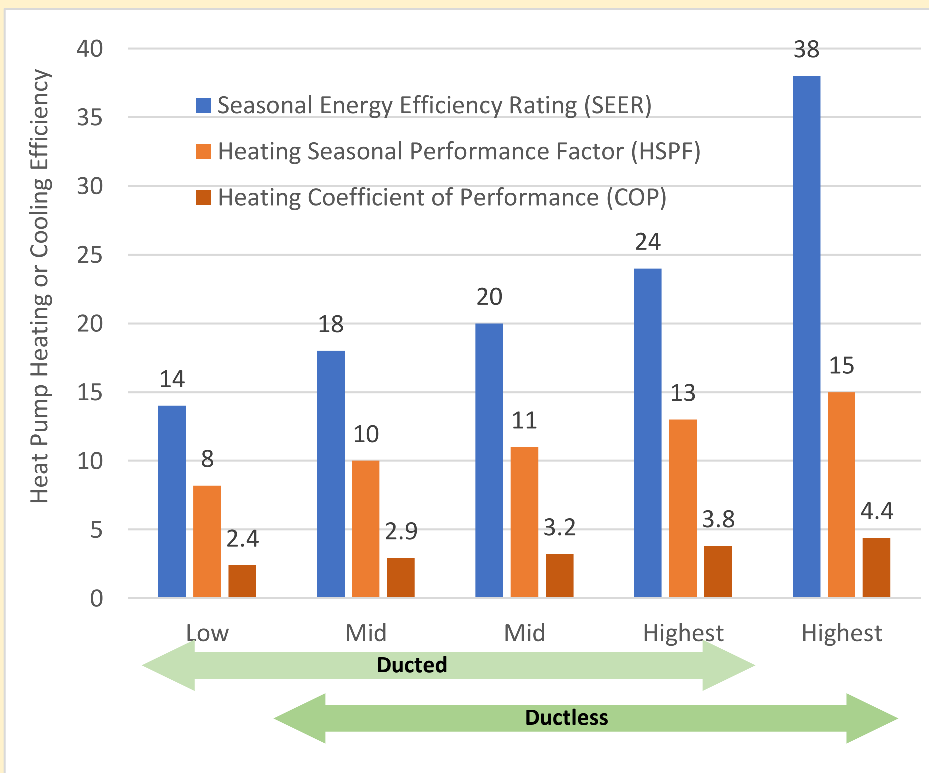


Figure 29: Typical heating and cooling efficiencies of heat pumps.

SEER: (Seasonal Energy Efficiency Rating) has units of Cooling BTUs provided per Watt-hour of electric use (SEER/3.412 = Seasonal cooling COP[91]) HSPF: (Heating Season Performance Factor) has units of Heating BTUs provided per Watt-hour of electric use (HSPF/3.412 = Seasonal heating COP[92])

Commercial: Air-to-Water Large Heat Pumps

These large heat pumps are for commercial applications and range in heating capacity up to 600,000 BTUh, and are generally used for space heating but can be applied to domestic hot water heating as well. Large heat pumps vary in function – from just heating, heating or cooling, and simultaneous heating and cooling, and with heat recovery. Heat recovery can greatly improve the efficiency of a system- but is not always applicable to all building types. Where heat recovery does make sense is in labs and hospitals, where a high air change rate is necessary so there is a lot of reheating of the air (with a hot water loop). The choice of heat pump depends on the building - if you have a building that is not going to have a lot of reheat then purchasing a single function heat pump that just does heating to replace the boiler and keeping the air cooled chillers on the roof can make financial sense.

There are more air to water heat pumps for smaller building and single family applications in a later section below.

Manufacturer and Product Image	**Carrier** AquaSnap 61AF 030-105 	**Carrier** AquaSnap 30RQM / 30RQP Size 160 	**Aermec** CPS 0704 NRP0700+WWB0350 	**Mitsubishi** Pury-EP72TNU-A(-BS) 
Description	**Just heating** High temperature monobloc with integrated hydraulic module	**Multi-purpose** High efficiency at part and full load heat pump with heating and cooling **(Available in different sizes)**	**Multi-purpose,** 4-pipe distribution. Space Heating and Cooling configuration type	**Multi-purpose** heat recovery heat pump with simultaneous heating and cooling
Voltage (V)	360 – 440 V	Range: 360-440V	-	208/230V
Dimension in (H/L/W)	-	Size 160: 90.4”/95”/91.4”	97”/156”/87” preliminary	-
Ref. Type	R-407C	R-410A	R-410A	R-410A
Ambient Temp. Range (F)	**-4** **(cold climate)**	-	45	23 - 126
Power (W)	-	80,000	48,500	3,800
Max Outlet Water Temp. (F)	149	-	163	-
Heating Cap. (BTUh)	*88,374 – 348,038*	617,597	711,432	80,000
Cooling Cap. (BTUh)	-	525,469	552,000 (46 Ton)	72,000
Heating (COP)	3.99 – 4.26	3.75	TER – 7.67	Ducted COP: 3.81/- Non-Ducted COP: 4.37
Cooling (COP)	-	EER: 2.76	TER – 7.67	Ducted EER: 13.4 Non-Ducted EER: 15.4

Commercial: Air-to-Water Large Heat Pump Boilers Continued

	RBI HP0275 	**Oilon** ChillHeat RE Heat Pumps 	**Motivair** MHP-LA 
Description	The RBI inverter air-to-water heat pump is equipped with variable speed inverter driven compressors, Enhanced Vapor Injection (EVI) compressor technology, and a high efficiency condenser. This allows for variable drive performance in extreme climates.	Best suited for heating and cooling of large residential buildings and industrial plants. Scroll Compressor technology is used, depending on the model the heat pump contains from one to three scroll compressors.	Modular air to water heat pump chiller/ scroll compressor For commercial spaces
Voltage (V)	460	400	460
Dimension (ft)	86H x 45W x 84L	8.86H x 2.98W x 5.15L	9.41L x 5.26W x 8.16H
Ref. Type	R 410a	R410A	R- 410 A
Ambient Temp. Range (F)	-20 - 120	-	5 - ?
Max Outlet Water Temp (F)	140	143.6	110
Power (W)	13,000-28,000	-	-
Amps (A)	60 MCA 70 MOPD	200-400	MCA 81 MOP 110 FLA 73
Heating Cap. (BTUh)	101,941- 288,226 @ 47F 66,345 - 188,981 @17F	716,549-143,399	218,000
Cooling Cap. (BTUh)	**129,661 – 203,681**	-	258,000
Heating (COP)	3.04 @ 47F Up to 2.14 @17F	-	-
Cooling (COP)	5.04 @IPVL	-	-

Commercial: Air-to-Water Large CO2 Heat Pumps

Similar to the heat pumps in the tables above, these heat pumps are typically used for the space heating of large commercial buildings or can be applied to large domestic hot water systems. These heat pumps vary from the ones above because they use CO2 as the refrigerant, allowing them to operate in low outdoor air temperatures and also produce hotter water, around 180F, which can be ideal to replace existing boilers.

Manufacturer and Product Image	**Lync** Aegis A - CO2 	**Mayekawa** **Unimo "Eco Cute"** HE-HWA-2HTC 	**Mitsubishi** Heat20 (QAHV-N136TAU-HPB(-BS)) 	**Mitsubishi** Q-ton ESA 30EH-25 
Description	CO2 Air Source Heat Pump for space conditioning and/or hot water	Air and Water source heat pump water heater	All-electric heat pump water heater	**Just heating** Combines rotary and scroll technologies making it the world's first two-stage compressor
Gallons	250, 350, 500	-	-	-
Voltage (V)	480V	480V	208/230V	380 – 415 V
Dimension (in)	**Size 250:** 72H x 104W x 41D **Size 350**: 75H x 138W x 50D **Size 500**: 75H x 138W x 50D	49.2W x 74.8L x 81.9H	70H x 48.063W x 29.94D	66.5H/53W/29.7D
Ref. Type	R744 (CO2)	R744 (CO2)	R744 (CO2)	R744 (CO2)
Ambient Temp. Range (F)	**-4 – 113** **(Cold Climate)**	14 – 110	**-13 - 109** **(Cold Climate)**	**-13 – 109** **(Cold Climate)**
Max Outlet Water Temp (F)	185°F	194°F	176°F	Intermediate season: 6,980 Cold Season: 10,730
Power (W)	**Size 250**: 16,100 W **Size 350**: 26,800 W **Size 500**: 41,900 W	22,600	40,000	140 - 194
Max Amps (A)	**FLA** **Size 250**: 35.4 A **Size 350**: 48.8 A **Size 500**: 73.8 A	120 A	30-27.2	Intermediate season: 102,364 Cold Season: 102,364
Heating Cap. (BTUh)	**Size 250**: 210,000 @ 77°F Air **Size 350**: 329,000 @ 77°F Air **Size 500**: 494,000 @ 77°F Air	200,634 @ 44.6°F Air 284,231 @ 77°F Air	136,480	-
Cooling Cap. (BTUh)	**Size 250**: 145,000 **Size 350**: 229,000 **Size 500**: 340,000	-	-	Intermediate season: 4.30 Cold Season: 2.80
Heating (COP)	**Size 250**: COP-3.8 **Size 350**: COP-3.6 **Size 500**: COP-3.5	COP-3.7@ 44.6°F Air COP-4.4 @ 77°F Air	4.11	-
Cooling (COP)	**Size 250**: TER - 6.4 **Size 350**: TER - 6.1 **Size 500**: TER - 6.0	-	-	-

Commercial: Water Source Heat Pumps

Water source heat pumps use the ground, a water source, or a water loop to grab heat from. They can also be paired with air source heat pumps in a cascading system, where heat is moved from the air into a water loop in the first stage, then the temperature is lifted again in the second stage with a water to water or water source heat pump.

Manufacturer and Product Image	**Lync** Aegis-W CO2 	**Multistack** MR010XN 	**ClimateMaster** Tranquility Modular TMW060 	**Nordic** W Series (W-400) 	**The Whalen Company** Closet Line Packaged 
Description	Extremely efficient heat pump using an environmentally friendly refrigerant (CO2).	Modular heat pump with reverse valves. Ideal for closed-loop and ground-loop water source heat-pump applications.	High Efficiency and high-capacity modular heat pump with advanced features and operates quietly.	Ideally for large scale radiant in-floor heating applications, swimming pool heating, ice rink cooling. heating and cooling	Horizontal and vertical configurations, compact, perfect for commercial retrofits or new commercial applications.
Gallons	250, 350, 500	-	-	-	-
Ref. Type	R-744 (CO2)	R-410A (Available with R-134a)	R-410A	R-410a	R410A
Power (V)	480V	208V	208-230V 460V 575V	208-575V	208/230 1-Phase to 575 3-phase
Source Water Temp. Range (°F)	14 - 60	<32	20 - 130	-	Cooling: 60 -100 Heating: 60 - 80
Max Outlet Water Temp (F)	185	-	140	130	-
Heating Cap. (BTUh)	Size 250: 199,000 Size 350: 319, 000 Size 500: 477, 000	60,000	Water Loop HP: 72,700 Ground Water HP: 60,300 Ground Loop HP: 48,500	Ground loop: 291,700 Ground Water: 408,600	Water Loop: 7,500-72,000 Ground Loop: 4,600- 49,00
Cooling Cap. (BTUh)	Size 250: 145,000 Size 350: 229,000 Size 500: 340,000	60,000	Water Loop HP: 52,800 Ground Water HP: 56,600 Ground Loop HP: 55,600	Ground Loop: 365,300 Ground Water: 393,000	Water Loop: 6,000- 58,000 Ground Loop: 6,300- 59,000
Heating (COP)	3.7 3.6 3.5	Can exceed COP – 5.0	Water Loop HP: COP- 4.6 Ground Water HP: COP- 3.8 Ground Loop HP: COP- 2.9	Ground loop: COP – 3.43 Ground Water: COP – 4.61	Water Loop: 2.9-5.6 Ground Loop: 3.4-4.0
Cooling (COP or EER)	3.7 3.6 3.5	Can exceed EER - 15	Water Loop HP: EER – 14 Ground Water HP: EER – 20.3 Ground Loop HP: EER – 15.1	Ground loop: EER – 16.6 Ground Water: EER – 21.6	Water Loop: EER 13.5 - 17.00 Ground Loop EER: 14.5 - 19.00

Commercial: Chillers

A chiller's function is in its name, to chill water. They have been used in the commercial HVAC industry for a long time and are typically used along side a boiler for heating. The two main categories of chillers are air cooled and water cooled. In addition, some chillers are designed for heat recovery- which is not applicable to all buildings, but can be very beneficial in some. Where is not a lot of potential for heat recovery in a particular building, it can be beneficial to use two separate heat pumps – one for heating and one for cooling (aka a chiller).

Air Cooled Chillers

Manufacturer and Product Image	**Swegon**[93] Cobalt Pro 	**Trascom**[94] Rawson Air-cooled Chiller 	**Cold Shot Chillers** [95] Stationary Air-Cooled Chiller ACWC-24-QST 	**Drake** [96] G800 800GLX Packaged Air-cooled Chiller, 180D-ZD 
Description	Air-cooled water chiller unit with semi-hermetic screw compressors and shell and tube evaporators.	Air cooled chiller with master controller that allows for multiple chillers to operate as on entity	Standard, Reverse & Continuous Flow Air-Cooled Chillers that is equipped with all the necessary components	Packaged air-cooled 20 HP dual circuit digital scroll with tank
Voltage (V)	415	208-230, 460, 575	460	460
Dimension (L /W / H)	Not available	65" / 34"/ 65"	Not available	85"/40"/73"
Capacity (tons)	-	32	Not available	Not available
Ref. Type	R134a	R410a	R410a	R407C/R404A
Ambient Temp. Range (F)	Up to 113°F	-5 F to 90°F	Not available	- 10°F to 45°F

Manufacturer and Product Image	**York**[97] 	**Daikin**[98] 	**Trane**[99] 
Description	With an environmentally friendly design that leads the industry, this high-efficiency unit uses innovative scroll compressor technology.	The first air-cooled screw chiller with IPLVs capable of exceeding 22 EER	The Series R helical rotary chiller is the workhorse of the Trane air-cooled portfolio a classic chiller with proven performance and reliability.
Ref. Type	R-410a	HFC-134a	R134-a
Power (V)	480	480	480
Ambient Temp. Range (°F)	Up to 125°F	Up to 130°F	25 F to 115°F
Capacity (tons)	500	565	500
Dimensions (L/W/H)	109"/44"/38"	179.3"/88"/100.1"	196"/86"/93.5"

Water Cooled Chillers

Manufacturer and Product Image	**Carrier**[100] 	**Carrier** AquaEdge 	**York**[101] 	**Advantage**[102] 	**Trane**[103] 
Description	Ensures the most cost-effective, reliable solution for today's comfort cooling and process cooling applications	The AquaEdge chiller's two-stage positive pressure Equidrive back-to-back compressor, coupled with ASME (American Society of mechanical Engineers) constructed heat exchangers, ensures high-reliability.	From schools to data centers, this water-cooled, centrifugal chiller delivers flexibility, performance and efficiency to any facility.	Stationary units designed to provide chilling capacity to new or existing central chilled water systems.	Optimus chillers support a broad range of cooling capacities to meet the needs of a myriad of different buildings and applications
Ref. Type	HFC-134a	R-514A or R-314a	R-134a or R-513A	R-410A	R-134a or R-513A
Power (V)	480	460	460	460	460
Ambient Temp. Range (°F)	0 F to 140°F	40-104	Up to 90°F	20°F to 70°F	10°F to 140°F
Capacity (tons)	1600	300-700	500	180	450
Dimensions (L/W/H)	197"/75"/84.8"	-	Not available	85"/73"/130"	274"/90.5"/64"

Commercial: Heat Recovery Chillers

A heat recovery chiller is where the heat of the condensing process is absorbed by a water loop and then used for heating. Heat recovery chillers typically utilize less energy than other common sources and outputs significantly less heat.[104]

Air Cooled

Manufacturer and Product Image	**Multistack** ARA 	**Carrier** AquaSnap 30RB 	**Motivair** MHR-A 	**Climacool** UCA 	**Ecochillers** ECTWSWHR 	**Ecochillers** ECTASHS 
Description	4-pipe, simultaneous heating and cooling, integrated heat recovery heat exchanger	Optional integrated hydronic pump package (with or without VFD), optional desuperheater and optional high-efficiency variable condenser fans.	simultaneous cooling & heating. Includes dual screw compressors designed to recover up to 100% of the available heat to a closed-circuit hot water loop.	Simultaneous heating and cooling heat pump with heat recovery.	heat recovery air-cooled chiller. Has VFD on compressor option	heat recovery option, inverter and digital compressors, VFD, electronic commutated motor fans, and pumps and water reservoir tank build in.
Ref. Type	-	R-410A	R-407C or R134a	R-410A	R-134a medium Temp, R404A low Temp	R-410A or R-404
Power (V)	-	-	-	208, 230, 460, 575	-	-
Max Output Water Temp (F)	130°F +	131°F	140°F	135°F	-	-
Capacity (tons)	-	60 to 190 Tons	60-500 Tons	20, 30, 50, 70	1 to 600 ton	60 to 600 ton
Dimensions (L/W/H)	-	**Size 060:** (94”/88”/90”) **Size 120:** (188”/88”/90”) **Size 300:** (423”/88”/90”) ***Note: up to 17 different sizes. Only 3 are listed here	**Size 200:** (140”/87”/83”) **Size 600:** (264”/87”/83”) **Size 950:** (482”/87”/99”) *** Note: 12 different sized available. Only 3 shown here	**Size 20 and 30 Ton:** 83.75”W/ 92”H/ 39.75”D **Size 50 and 70 Ton:** 83.75”W/ 99.125”H/ 80.5”D	**-**	**-**

Water Cooled

Manufacturer and Product Image	**Ecochillers** ECTWSW 	**Ecochillers** ECTWSWHR 	**Multistack** 	**Carrier** AquaSnap 30 	**Carrier** AquaForce 30XW 	**Climacool** UCH 
Description	Easy to start up and operate water-cooled chiller with heat recovery and VFD compressor on options	Easy to start up and operate heat recovery air-cooled chiller. Has VFD on compressor option	Water-cooled MagLev chiller with oil-free, magnetic levitation bearings in a high-lift centrifugal compressor is a leader in efficiency, reliability, redundancy, sustainability, and serviceability.	packaged liquid and condenser less chillers feature a compact modular design that makes them ideal for easy replacement, retrofit, or new construction applications.	High-efficiency, indoor water-cooled chillers with a quiet, low vibration design featuring screw compressors. Low energy consumption during part load nd full load operation.	Simultaneous heating and cooling heat pump with heat recovery. Helps reduce energy consumption.
Ref. Type	R-134 medium Temp, R404A low Temp	R-134a medium Temp, R404A low Temp	-	R-410A	R-134a	R-410A or R-134a
Power (V)	-	-	-	-	Available operational voltages: 200, 230, 380,460, 575	208, 230, 460, 575
Max Output Water Temp (F)	-	-	145°F	140°F	140°F	135°F (R-410A) or 165°F (R134a)
Capacity (tons)	60 to 600 ton	1 to 600 ton	Starting @ 80 Ton	16 to 71 Nominal Tons	150 to 400 Nominal Tons	15, 25, 30, 50, 70, 85
Dimensions (L/W/H)	-	-	-	**Module 016-045:** (55”/32”/62.5”) **Module 050-071:** (55”/32”/66.3”) **Distribution Panel:** (55”/32”/70.25)	Unit width of 48” or less	**Size 15,25,30,550, 70:** 34.25”W/78” H/55.5”D **Size 85:** 34.25”W/84. 875”H/67”D

Commercial: Split Systems

Split systems are similar to the typical split systems in a residential setting, except larger. Some are cooling only, while others provide both heating and cooling.

Manufacturer and Product Image	**Carrier** Gemini Split-System Heat Pump 38AUQ (Outdoor Unit) 	**York** YD 30-50 Ton Split Condensing Unit (Outdoor Unit) 	**Lennox** Elite ELP Series 7.5 & 10 Ton HP (Outdoor Unit) 
Description	All Gemini 38AUQ condensing unit and 40RU Fan coils (indoor units) use environmentally sound Puron refrigerant. The Condensing Unit can be rooftop or ground level installation.	The durable York YD 30-50 condensing units have a compact design and clean style. They are ideal for rooftop or ground level installation. In addition, the YD 30-50 is easy to install and operates quietly. **(Cooling Only)**	Lennox Elite Series offers superior comfort and energy savings. Includes 2-stage cooling allow the system to respond to changing conditions efficiently and effectively. Also operates at low speeds most of the time offering quiet operation. Includes Merv 8 filter and VFD.
Voltage	240, 480, 575	208/230-3-60 460-3-60 575-3-60	-
Dimensions (in) L x W x H	59L x 46W x 42H	**30 Ton**: 128.5L x 88.5W x 37.5H **40 Ton**: 128.5L x 88.5W x 57.7H **50 Ton**: 128.5L x 88.5W x 57.7H	**7.5 Ton**: 44L x 40W x 49H **10 Ton**: 44L x 61W x 49H
Ref. Type	R-410A	R-410A	-
Ambient Temp. Range (F)	35°F – 125°F	40°F – 125°F	<0°F
Power (kW)	6.4 kW	**30 Ton**: 29.9 kW **40 Ton**: 37.4 kW **50 Ton**: 50.0 kW	-
Heating Cap. (BTUh)	66,000 @47°F	-	**7.5 Ton**: 87,000 **10 Ton**: 114,000
Cooling Capacity. (BTUh)	70,000	**30 Ton**: 333,000 **40 Ton**: 469,000 **50 Ton**: 576,000	**7.5 Ton**: 88,000 **10 Ton**: 115,000
Heating (COP)	3.30	-	**7.5 Ton**: 3.3 **10 Ton**: 3.3
Cooling (EER/IEER)	11/12.6	**30 Ton**: 10/11.1 **40 Ton**: 10/10.8 **50 Ton**: 10/10.4	**7.5 Ton**: 11/13.6 **10 Ton**: 11/13.6

Commercial: Packaged Rooftop Units

Rooftop units contain all elements of a heating and cooling system- the heating and cooling elements, as well as the ability to move air in and out of the building. They are very common in mid-sized commercial buildings and typically use electricity for cooling but a gas furnace for heating. Most manufactures make heat pump versions that use electricity for both the heating and cooling, making electrification straight forward for building that use them.

Manufacturer and Product Image	Carrier 	Daikin 	Johnson Series 5 	KwiKool 
Voltage	208/230	460	208/230	460
Dimensions (in) L x W x H	74 x 47 x 33	91 x 56.8 x 96.5	82 x 44 x 32	66 x 66 x 60
Ref. Type	R-410A	R-410A	R-140A	R-407C
Ambient Temp. Range (F)	**17 – 115 F**	**40 – 95 F**	**-10 – 60 F (cold climate)**	**30 - 110 F**
Power (kW)	3.1	5.81	3.13	42.6
Heating Cap. (BTUh)	34,000	38,861	35,000	270,000
Cooling Capacity. (BTUh)	36,200	100,114	36,200	166,600
Heating (COP)	3.70		3.10	3.90
Cooling (COP)	2.25		2.15	2.15

Manufacturer and Product Image	**Carrier** WeatherMaker 50TCQ (17,24) 	**York Sun Core** 	Bryant Heating and cooling 	Rheem Renaissance 
Description	Units is pre-wired and pre charged	Smart Equipment controls aid in reliability and ease of use	Single and multi- stage cooling and heating models are available	The Renaissance series is compact and cost effective, with convertible airflow.
Voltage (V)	460/3/60	-	-	208/460/575
Ref. Type	R-410A	R410a	R-410A	R-410A
Ambient Temp. Range (F)	**30 F -115 F**	**40 F-125 F**	**-10 F to 130 F (cold climate)**	125 (high)
Power (W)	16.2-21.9	2.9 - 8.3 kW	17-43.5 Kw	-
Heating Cap. (BTUh)	160,000 – 220,000	84,000-108,000	34,000-116,00	86,000- 114,000 High Temp 48,000- 72,000 Low Temp
Cooling Cap. (BTUh)	180,000 – 240,000	36,400 – 101,000	39,000-119,000	89,000-114,000
Heating (COP)	2.30 – 3.30	3.2-4.7	2.4 -2.9	3.3 High Temp 2.3 Low Temp
Cooling (COP)	3.10 – 3.16	3.2-3.5	3.5-4.5	3.23

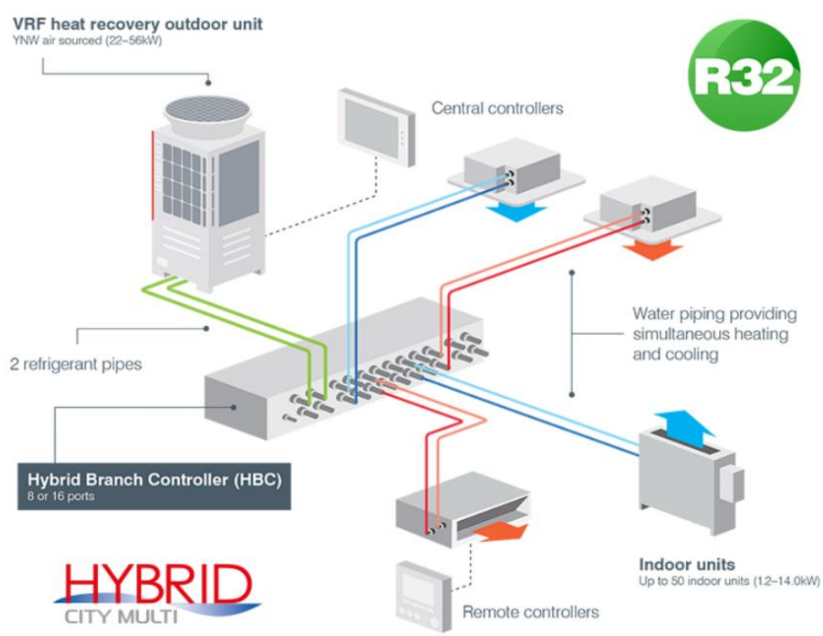
Variable Refrigerant Flow Heat Pumps (240V)

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.

Manufacturer and Product Image	**Mitsubishi** City Multi Y-Series 	**Daikin** VRV IV Heat Pump 	**York** Gen II Heat Recovery 	**Carrier** VRF 38VMH 	**Mitsubishi** Hybrid VRF 
Voltage (V)	208/230	208/230V - 460V	208/230V - 460V	208/230V	208-230V/460V
Dimension (ft)	5.4H x 5.7W x 2.4D	(66-11/16 x 36-11/16 x 30-3/16) - (66-11/16 x 48-7/8 x 30-3/16)	66 ¼ x (38-3/8, 48-5/8, 64) x 30-1/2	64-3/8 x 52-¾ x 31-7/64	(71-5/8 x 36-1/4 x 29-5/32) - (71-5/8 x 68-29/32 x 29-5/32)
Ref. Type	R410A	R410A	-	R410a	R32
Ambient Temp. Range (H/C) (F)	**-13 – 60 / 12 – 115 (cold climate)**	**-4 – 122 (cold climate)**	**-13 – 122 (cold climate)**	**-5 – 125 (cold climate)**	**-13-60/23-126**
Power (W)	5,700 - 12,200	21kW - 135kW	-	-	22,000-56,000
Max Amps (A)	23 - 53	27.6 - 146	-	-	-
Heating Cap. (BTUh)	80,000 – 405,000	73,000 - 435,000	81,000 - 216,000	80,000 - 108,000	80,000 – 188,000
Cooling Cap. (BTUh)	72,000 – 360,000	73,000 - 372,000	72,000 - 192,000	72,000 - 96,000	72,000-168,000
Heating (COP)	3.56 – 4.22	3.4	2.05 - 4.25	-	3.76-4.09
Cooling (COP)	3.40 – 4.16	3.4	-	-	3.76-4.09

Product Highlight: What is a VRF Heat Recovery Hybrid system?[105]

A VRF hybrid system is a, "unique 2-Pipe Heat Recovery VRF system that replaces refrigerant with branch circuit controller and the indoor units." It is an energy efficient simultaneous heating and cooling decentralized system In addition, it also minimizes leak detection services which are expensive as they can be on-going. It is a flexible and easy system to design and install utilizing the same control and network as traditional VRF systems. The hybrid VRF provides the figure below shows the Mitsubishi R32 Hybrid Heat Recovery VRF system.



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/h)	18,000 - 59,000	22,000 – 59,500	44,500	25,000
Cooling Cap. (BTU/h)	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 much less 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 5: "Belly Band" crankcase heater (heating wire wrapped around compressor).

Figure 6: 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 always 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."

120V Air Handlers

Typical air handlers for furnaces are 120V, but typical air handlers for heat pumps are 240V. Supplying 240V electricity for a fan is overkill, and a relic of the era before 2009 inverter-controlled heat pumps allowed heat pumps to avoid resistance heat when the temperature dropped below freezing. This is no longer needed and some manufacturers, like Mitsubishi[106], Mr. Cool, and Fujitsu supply 240V power via a wire from the outdoor 240V compressor/condenser. However, below are 120V heat pump air handlers that can use the existing furnace fan wiring, avoiding the need to run a new wire.

Manufacturer and Product Image	**Advanced Distributor Products B Series Air Handler**[107] 	**Stelpro** SCV-P-1411[108] 	**King Electrical Mfg. Co.** AH1/5-120V[109] 
Price ($)	Not public	$925	$965
CFM	800	1400	1000
Size (in) LxWxH	22 x 15 x 44	24.75 x 22 x 22	20 x 16 x 30.5

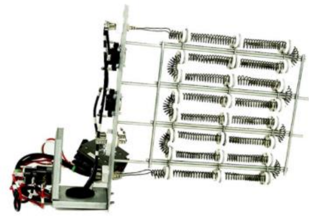
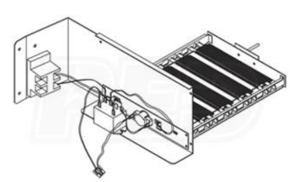
Cold Climate Back Up: Electric Resistance for Air Handlers

Nate Adams of Energy Smart Ohio:

"Most unitary (standard split heat pump) systems have electric resistance back up option. It's very important for dehumidification in humid climates, but also serves to backup the heat pump in very cold temps, allowing for more aggressive sizing. Our heat loads in Cleveland are ~2X cooling loads. So we usually size between the two and lean on resistance. Without TOU rates, this is the best customer centric strategy."

"A 200-amp service is the best recommendation for houses 3000 square feet and under (basically that can run on one HVAC system.) We've done 2 electrifications on 100-amp panels though, one even had an EV. We had to use smaller heat strips."

"If they have a 100-amp panel we use a 3 stage 3/6/9 kW backup heat strip."
"If they have a 200-amp panel we use a 3 stage 5/10/15 kW backup heat strip."

Manufacturer and Product Image	Mr. Cool Universal Series Air Handler Electric Heat Kit 	LG Electric Heater ANEH033B1 
Power (kW)	5 kW, 8 kW, 15 kW	3, 5, 8, 10, 15
Size (HxWxL) in	5 x 9 x 9	
Cost	$70 - 160	$140 - 290

Mini-Split Heat Pumps (240V)

Figure 30: An example of a ductless mini-split heat pump outdoor compressor[110] mounted to stay above the snow and a wall-mounted indoor fan coil[111].

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.

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 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 1 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 a number of 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 an hour to $35 an hour, and sold to the client at $42 an hour 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 vary 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 1: 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 2: 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 maintenance 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 companies 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 utility programs with any simple pricing model to use.

Ductless Mini-Split Heat Pumps (120V)

Interior Wall-Mounted Fan Coil 	**GE** Caliber Series AS12CRA 	**Mitsubishi** MZ-JP12WA 	**Gree** LIV (09,12) HP115V1B 	**Carrier** 38MAR 	**Haier** 
Description	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil	1 Indoor Fan Coil
Dimension (in) (HxWxD)	21 x 31 x 10	22 x 32 x 11	33 x 21 x 13	32 x 21 x 13	28 x 35 x 14
Ref. Type	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-4 - 115**	**-4 - 115**	**0 - 115**	**-13 - 122**	**-4 – 115**
Crankcase Heater	Not Indicated		Not Indicated	Not Indicated	Not Indicated
Power (W)		800 – 1,300	1,955	1,725	2,100
Max Amps (A)		11.8	17	15	18
Heating Cap. (BTU/h)	12,000	12,200	9,600; 12,500	12,000	16,000
Cooling Cap. (BTU/h)	12,000	12,000	9,000; 12,000	12,000	12,000
Heating (COP)	2.92	2.9	3.3	2.03 - 3.80	3.2
Cooling (COP)	2.92	2.9	4.67	3.8	3.75
Price ($)	$860	$1200	$790	$1800	

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**[112] 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	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**
Crankcase Heater	Not Indicated	Not Indicated	Not Indicated	Not Indicated	Not Indicated
Power (W)	230 – 2,160	1,330 – 2,700	1,380 – 1,480	1090 – 3070	970 – 6,020
Max Amps (A)		16.4 - 26	13.6	14.8	23
Heating Cap. (BTU/h)	23,000	9,000 – 36,400	10,900 – 30,700	24,000 – 54,000	15,840 – 61,000
Cooling Cap. (BTU/h)	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

Attic Fan Coil and Ductwork 	**Senville** SENA/18HF/ID 	**Carrier** 38MGQC183 	**Gree** MULTI18HP230V1BO 	**Mitsubishi** MXZ3C24NAHZ2 
Indoor Unit Dimension (in)	34.7 x 28.5 x 8.27	36.2 x 8.3 x 25.0	35.4 x 7.9 x 24.2	37.4 x 16.4
Outdoor Unit Dimension (in)	33.3 x 14.3 x 27.64	33.3 x 27.6 x 12.6	38.0 x 27.6 x 15.6	41.3 x 37.4 x 13.0
Ref. Type	R410A	R410A	R410A	R410A
Ambient Temp. Range (F)	**-22 (cold climate)**	4 - 122	**-4 – 118 (cold climate)**	**-13 – 115 (cold climate)**
Crankcase Heater	Not Indicated	Not Indicated	Not Indicated	Not Indicated
Max Amps (A)	25	20	25	40
Heating Cap. (BTU/h)	18,000	18,500	19,000	25,000
Cooling Cap. (BTU/h)	17,000	17,500	18,000	22,000
Heating (COP)	3.0	2.8	2.6	2.6
Cooling (COP)	4.2	4.2	4.1	4.5
Per Indoor Unit Piping Length (ft)	98	98	65	82
Price for Outdoor Unit ($)	$ 1,400 (includes 50 ft refrigerant line)	$ 1,760 (no refrigerant lines)	$ 1,930 (no indoor units or refrigerant lines)	$ 3,110 (no ducting 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)**
Crankcase Heater	Not Indicated	Not Indicated	Not Indicated	Not Indicated
Max Amps (A)	15	29.5	15	15
Heating Cap. (BTU/h)	12,000	13,700	16,000	16,000
Cooling Cap. (BTU/h)	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)

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.

(120V) Packaged Terminal Heat Pumps

Manufacturer and Product Image	**Innova** HPAC 2.0 	**Olimpia** Maestro 	**Frigidaire** FFRH1122UE 	**Friedrich** YS10N10C 	**Gree** 26TTW09HP115V1A 
Description	Twin ducts through the wall, dehumidification, Resistance back-up	Twin ducts through the wall, dehumidification	Heat pump with Resistance (ER)	Heat pump model – no back up Resistance	Heat pump model with Resistance (ER)
Voltage (V)	120	120	120	120	120
Dimension (in)	1.8H x 3.3W x 0.5D	-	15H X 22W x 23D	15H x 25W x 29D	15H x 26W x 16D
Ref. Type	R410a	R410a	R410a	R410a	R410a
Min. Heat Pump Operating Temp (F)	**-14 (cold climate)**	**5 (cold climate)**	40	40	29
Power (W)	545 – 730	830-850	780 – 1,290	917 - 978	830 – 1,150
Heating Capacity (BTU/h)	3,100 - 10,000	10,600 (Heat Pump only)	9,900 (HP) 3,500 (ER)	8,000	6,600 (HP) 3,900 (ER)
Cooling Cap. (BTU/h)	2,600 - 10,000	11,600	11,000	10,000	9,000
Heating (COP)	2.84 – 3.22	3.8	2.63	2.6	3
Cooling (COP)	3.12 – 3.28	3.8	2.87	3.19	2.87
Price ($)	$1950	$1700-$2300	$ 700	$ 1000	$ 700

(240V) Packaged Terminal Heat Pumps

Manufacturer and Product Image	**Amana** AH (093,123,183) 	**Friedrich** Y (S12, M18, L2) 	**Gree** W (07,09,12) 	**LG** LP (073,093,123,153) 
Description	Heat pump model	Heat pump model – no back up ER	Heat pump model with ER + dehumidification	Heat Pump with ER, but HP functions in cold climates
Voltage (V)	208/230	230/208	230	208/230
Dimension (in)	16H x 26W x 27D	20H x 28W x 35D	15H x 26W x 16D	16H x 42W x 21D in
Ref. Type	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	61 - 86	60 - 115	29 - 125	**-4 - 75 / 54 – 115 (cold climate)**
Power (W)	920 – 3,680	1,100 – 2,400	680 – 3,500	2,300 - 4,700
Amps (A)	4.2 – 16.0	4.9 – 19.5	3.0 – 15.2	15,20, 30-amp cord
Heating Capacity (BTU/h)	10,700 – 9,000 (ER) 8,100 – 16,00 (HP)	11,300 – 22,000	3,900 – 11,000 (ER) 6,600 – 11,400 (HP)	6200- 13,400
Cooling Cap. (BTU/h)	9,200 – 17,300	12,000 – 24,00	7,200 – 11,700	7,100 – 14,900
Heating (COP)	2.6 - 2.9	2.6 -2.7	2.9 – 3.1	3.1 – 3.5
Cooling (COP)	2.63 – 2.93	3.02 – 3.19	2.81 – 3.11	3.28 – 3.90
Price ($)	$ 700 - 1,250	$ 1,000 - 1,500	$ 930	$ 1,000 – 2,000

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

VTAC's sit vertically in a closest and provide heating and cooling through ducting to a space without having visible units hanging on the wall.

Manufacturer and Product Image	**IceAir** SPXC (12,18,24) 	**Amana** AVH123H 25A,35A,50A 	**GE** AZ75H (09,12,18) EAC 	**Islandaire** EZ (09,12,15,18) 	**Friedrich** VRP 
Description	Air to Air	Air to Air	Air to Air	Air to Air	Air to Air
Voltage (V)	208	208 / 230	208 / 230 or 265	208 - 277	230/208 - 265
Dimension (in) (HxWxD)	24 x 33 x 23	32 x 23 x 23	32 x 23 x 23	23 x 29 x 24	31 3/4" x 29 7/8" x 77 1/4" (largest size)
Ref. Type	R410a	R410a	R410a	R410a	R410a
Ambient Temp. Range (H/C) (F)	**-5 - 95**	AHRI Certified to 47F Heating	25F switches to electric heat	38F shuts off, optional resistance can turn on	**0 - 70**
Power (W)	884 - 2200	2,100 – 5,000	1510 - 4910	685 - 1510	991 - 2570
Max Amps (A)	18.8	15 - 29	21.8		4.3 - 14.2
Heating Cap. (BTUh)	7,600 – 25,900	7,000 – 17,000	8,400 – 15,700	8,400 – 15,500	11,400 – 28,500
Cooling Cap. (BTUh)	9,700 – 25,600	-	9,500 – 17,500	8,900 – 17,500	12,00 – 33,400
Heating (COP)	3.5	3.0	2.5 – 3.6	3.3	2.2 - 2.4
Cooling (COP)	3.8	-	2.9 – 3.1	3.0	3.2
Price		~$1900	$1650-1850	-	$2800

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 ERVs 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.113 The goal with an HRV is 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 need for an HRV or ERV.

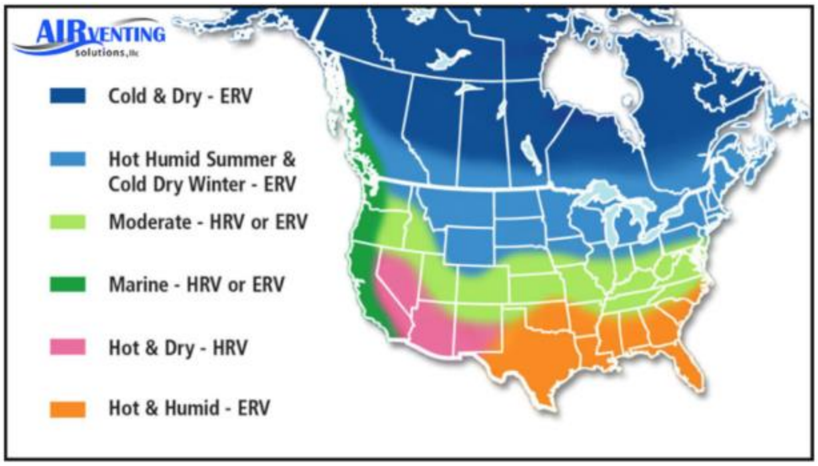


Figure 31: Choosing an HRV or ERV system based on location map.[114]

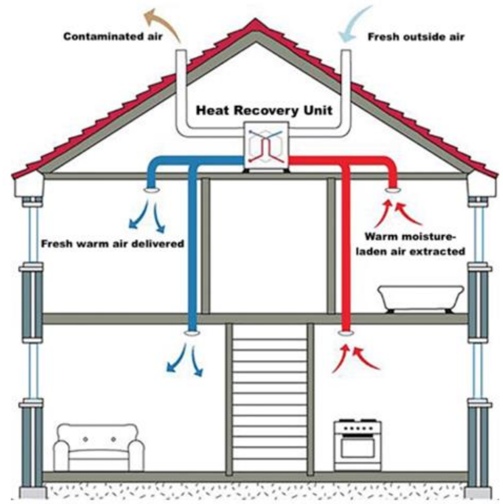
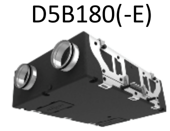


Figure 32: Heat Recovery ventilation system example.[115]

The unit operates continuously, sucking air through ducts that are positioned in prime generation locations of moisture and odor ex. bathrooms and kitchen. 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.

Single Family Multifamily Sized:

Manufacturer and Product Image	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%

Commercial Heat Recovery Ventilation

Description of Ventacity Strategy

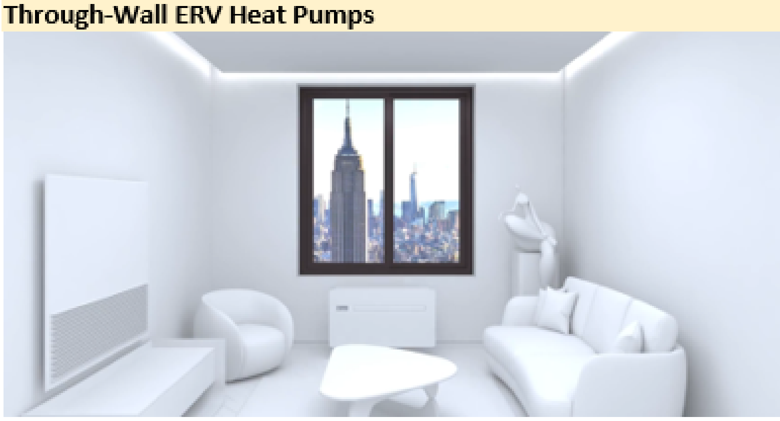
Ventacity provides energy management for small to mid-sized commercial buildings through upgrading HVAC systems with improved ventilation and controls. The company pursues several retrofit strategies which increase occupant health along with energy efficiency. One of these strategies is to separate ventilation from heating and cooling systems – while it may seem logical to combine these systems, the duct system for heating and cooling is oversized for ventilation, and each system has different preferred supply and exhaust locations. Another effective strategy is to remove aging RTUs and installing new, more efficient VRF and HRV systems. This allows buildings to meet heating and cooling needs with smaller systems, that use significantly less energy and result in lower indoor concentration of CO_2.

Manufacturer and Product Image	Carrier Performance HRVCRSVU 	Lifebreath RNC5-TPD Residential 	Broan B6LCDPRN 	GeneralAire HRV 8160, HRV 8220 
Description				
Voltage (V)	115V	120V	120V	120V
Dimension (ft)	24.625"H x 23.625"W x 15"D	17 ¼ "H x 22 ¾ "W x 14"D	24"H x 34"W x 28"L	(23.875 D x 21.5 H x 11.375 W) - (23.875 D x 21.5 H x 16.5 W)
Airflow	157 cubic feet/minute	136 CFM	470 – 720 CFM	30 – 220 CFM
Heating Recovery Efficiency	78% at 32F	68% at 32F		
Ref. Type				
Max Inlet Temp (F)			150F	
Power (W)		69 - 147W		130-150W
Amps (A)		1.2A	5.7A	1.5A

Single Family Sized ERV, HRV, and Heat Pump Combined Products

Manufacturer and Product Image	**CERV-2** 	**Minotair** Pentacare V12 	**ephoca** xK92NSGx 
Description	Ducted Ventilation and Heat Pump – HRV Combo	Ducted Heat Pump, HRV, and Ventilation (MERV-15) Combo with 5kW resistance heat	Ducted Ventilation, Heat Pump, ERV, MERV-13 filtration
Unit Dim. (in) (HxWxD)	38 x 25.5 x 40	16 x 18 x 40	39 x 38 x 10
Refrigerant	R410a	R410a	R410a
Ambient Temp Range (F)	**No low temperature cutoff**	**No Low Temperature cutoff, resistance heater is controlled for efficiency**	**-5F**
Voltage	120V	120V / 240V	240V (120V available)
Max Amps (A)	12A	6.6A (HP-only), 27A Max	15
Heating Cap. (BTU/h)	9,720 (17F) – 11,262 (47F)	5,600 (17F) – 8,700 (47F)	10,300 – 16,600 (47F)
Cooling Cap. (BTU/h)	7,544 (95F)	11,200 (95F)	3,100 – 10,500
Heating (COP)	2.8 – 3.6	2.4 (17F) – 3.0 (47F)	4.0
Cooling (COP)	3.2	3.3 (95F)	3.6
Price for Unit	-	$6000	-

Through-Wall ERV Heat Pumps



Manufacturer/Model	Ephoca/AIO
Unit Dim. (in) (HxWxD)	39.7 x 6.5 x 21.9
Refrigerant	R32 or R410a
Lowest Rated Temp (F)	13
Heating Cap. (BTU/h)	3,000 – 14,900
Cooling Cap. (BTU/h)	3,200 – 15,100
Heating (COP)	1.77-3.52
Cooling (COP)	3.30-3.42

Some manufacturers of heat pump technology have developed a single, indoor unit that can provide heating and cooling to single family homes, such as Ephoca's wall mounted AIO model pictured above. The unit accesses outdoor air through ventilation ducts cut directly through the wall at the location of mounting and performs an Air-to-Air heat transfer to provide HVAC services. The design is low impact and requires minimal installation costs or hardware. It is advantageous in situations where an external unit is not possible to install or where decentralized HVAC is preferred. However, this model is not suited for larger spaces or non-residential use and its higher operating temperatures mean it is not ideal for cold climates. *This model is well-suited to apartments and small commercial spaces or distributed in multiple rooms of a house. *

Portable Heat Pumps (120V)

Heat pumps can come on wheels for those who want to electrify their space heating but may not have the budget or permission from the landlord to install a permanent, whole house solution.

These retrofit-ready heat pumps can plug into any outlet in a home and come with ducts that fit into an open window. The ducts allow outside air to be pulled in as a heat source or sink and then exhausted while the heat pump heats or cools the inside air. They can do additional work as powerful dehumidifiers, with a storage tank and/or condensate drain line.

Figure 33: A "two-pipe" portable heat pump.

Manufacturer and Product Image	**Edge Star** 	**Black + Decker** BPACT12HWT 	**Whynter** ARC-14SH 	**Haier** HPND14XHT 	**ClimaTemp** CPTH-12 
Voltage	120V	120V	120V	120V	115V
Power (W)	1250W (cool)/ 1200W (heat)	-	1250W	1260W (cooling)	1500 cooling 1200 heating
Max Amps (A)	-	9A	10.8A	11.4A	15
Dehumidifying Capacity	85 pints/day	-	101 pints/day	88.8 pints/day	-
Heating Capacity (BTU/h)	14,000	10,000 and 11,000	13,000	10,000	10,300
Cooling Capacity (BTU/h)	14,000	14,000	14,000	14,000	11,500
Temperature Range F (Output)	61 - 89	55 - 81F	61 - 89	61 – 100 *(can go below freezing at lower capacities)*	55 -80
Refrigerant	R410a	R410a	R32	R410a	R- 410A
Dimensions (in) (HxWxD)	35 x 19 x 16	28 x 17 x 14	36 x 19 x 16	29 x 15 x 17	41.7 x 19 x 26.5
Price	TBA	$697	$575	$670	-

A short study was conducted by Redwood Energy to compare the leading brands of portable heat pumps, for roughly a month in Arcata, CA during the months February and March. In summary the Whynter performed the best, however it discharged a large amount of water each day which became a hassle to dump every few hours (keep in mind the weather in Arcata is very humid).The Whynter used roughly 15 kwh/day and was so effective at heating the space the gas furnace was not turned on during its test period and the homeowner decided to keep it after the test period was over.

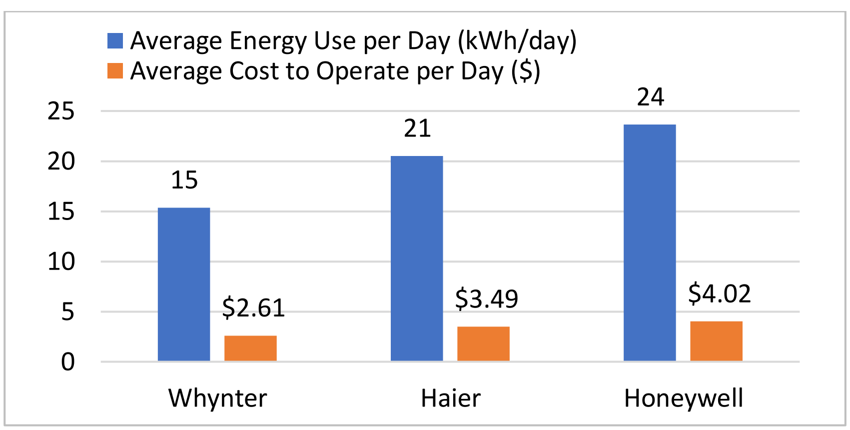


Figure 34: Test results comparing three leading brands of portable heat pumps, tested for a few weeks in Arcata, CA during February-March.

Hydronic Heat Pump Systems (Air-to-Water) (240V)

Air-to-water (ATW) heat pumps are utilized to perform the duties of both an HVAC and DHW system for residential and commercial building needs. These systems utilize heated or cooled water to provide HVAC services by running waterlines through the walls and floors of a home. The industry standard for these models also have designated hot water lines for DHW needs, some with the capacity to even heat swimming pools or hot tubs. The system commonly consists of an outdoor heat exchanger and a component indoors that controls fluid flow and storage but can also come as a singular outdoor unit. For some models, a separate storage tank for DHW is required while in others it is integrated into the internal or external heat exchanger.

Manufacturer and Model	**Spacepak** SIS	**Aermec AN** (030,045,050)	**Chiltrix** CX34	**Arctic** 020A	**Enertech** EAV60	**Mitsubishi** Ecodan + **Thermo-Plus** Hydrotank
External Component Image						
Description	Split ATW heat pump and water heater, high operating temp range and output	ATW heat pump with automated VMF system	Air to Water Heat Pump	Hydronic Heating, Domestic Hot Water, Pools and hot tubs	ATW heat pump with compressor resilient COP	ATW heat pump with integrated water storage and remote temperature variability
Dimension (in) (HxWxD)	54.7 x 35.5 x 15.6	50 x 58 x 18	38.15 x 43.9 x 16.74	33 x 18.5 x 45	44.5 x 50.3 x 24.1	31.9 x 28.1 x 11.8
Hydronic Heat Exchanger		No External Heat Exchanger	Optional Booster Heat Exchanger	No External Heat Exchanger		
Dimensions (in) (HxWxDx)	29.5 x 17.3 x 13.6	N/A	**N/A**	**N/A**	54.0 x 28.1 x 13.5	63.0 x 28.3 x 28.3
Ref. Type	R410a	R134a	R410a	R410a	R410a	R32
Lowest Rated Operational Temp (F)	**-20 (cold climate)**	**-4 (cold climate)**	**-4 (cold climate)**	**-15 (cold climate)**	**17**	**5**
Power (W)	230	2,810 – 4,520	360 - 2,360	2,710 - 3,000	14,960 – 18,400	N/A
Max Amps (A)	15	45	15	15	80	N/A
Heating Cap. (BTU/h)	20,500 – 71,600	37,670 – 57,598	4,000 - 33,800	35,826	55,000	8,900 – 23,000
Cooling Cap. (BTU/h)	30,000 – 62,400	30,120 – 48,240	4,000 – 30,000	25,600	37,900	10,000-22,000
Heating (COP)	3.09	3. 1 – 4.4	3.92	3.14	4.83	2.8-3.55
Cooling (COP)	3.66	N/A	6.75	2.5	3.44	4.1-4.74
Maximum Water Temperature (F)	120	113	122	140	140	130
Price		$5500-$7500	$4300	$3750	-	

Manufacturer and Model	**Hi-Sense** Hi-Therma	**Stiebel Eltron**WPL (15,20,25) (AS, ACS)	**Nordic** ATW-25-HACW-P-1T	**Nyle** C25A – C250A
External Component Image				
Description	ATW heat pump	Split system tankless ATW heat pump with DHW	Hydronic heating, fan coils air-conditioning	Multi-home/ Commercial Air to Water Heat Pump
Dimension (in) (HxWxD)	31.5 (54.3 for larger unit) x 47.4 x 14.6	41 x 59 x 23	38.1 x 33.8 x 22.1	24.8 x 45.3 x 30.3
Hydronic Heat Exchanger				No External Heat Exchanger
Dimensions (in) (HxWxDx)	N/A	15.6 x 14.5 x 4.6	29 x 28 x 28	N/A
Ref. Type	R32	R410a	R410a	R134a
Lowest Rated Operational Temp(F)	**-4 (cold climate)**	**-4 (cold climate)**	**-7 (cold climate)**	**35**
Power (W)	7,000 – 16,000	1,090 -7,530	1,190 – 2,500	5,500 - 24,000
Max Amps (A)	N/A	7.9 - 30	15 - 30	28 - 150
Heating Cap. (BTU/h)	23,800-54,500	8,525 – 46,500	4,280 – 22,700	27,500 – 272,500
Cooling Cap. (BTU/h)	22,100-46,000	7,330 – 58,000	17,400	21,200 – 218,000
Heating (COP)	4.5-4.74	1.85-5.09	1.38 - 4.94	4.58 – 5.33
Cooling (COP)	2.53-3.0	2.39-3.76	1.57 - 5.84	3.88 – 4.33
Maximum Water Temperature (F)	140	92	120	160
Price	N/A	N/A	$5000	N/A

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/h)	15,200 – 23,000	13,000 – 78,000	14,000-85,000	16400-19500	20,500-80,000
Cooling Cap. (BTU/h)	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

Electric Cooking

Overview: Full Scale Commercial Kitchen Equipment:

There are commercial kitchen options for all cooking traditions--Tandoor ovens for Pakistani dishes, induction woks for Chinese dishes, high-temp ovens for traditional Italian pizza, and exacting ovens for perfect French pastries. Below you will find commercial kitchen equipment types and the manufacturers who provide them.

			
Braising Pan/Tilt Skillet *Accutemp, Cleveland, Groen, Vulcan*	**Pressure Braising Pan** *Firex, Rational*	**Charbroiler** *Emberglo, Garland, Star, Wells*	**Clam Shell Griddle** *Garland, Keating, Lang, Taylor*

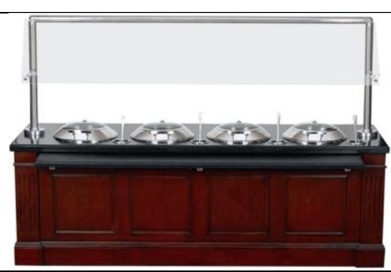
			
Convection Oven *Bakers Pride, Blodgett, Garland, Vulcan*	**Conveyor Oven** *Lincoln, Ovention, Turbochef, Merry Kitchen*	**Deck/Hearth Oven** *Bakers Pride, Baxter, Doyon, Lang, Revent, Sveba Dahlen, Pizza Master*	**Fryers** *Anets, Dean, Frymaster, Garland, Henny Penny, Imperial Range, Keating, Pitco, Vulcan*

			
Griddles *Evo, Garland, Keating, Lang, Vulcan, Accutemp*	**Kettles** *Cleveland, Groen, Market Forge, Vulcan*	**Pasta Cookers** *Arbobaleno, Keating, Pitco*	**Dome Pizza Ovens** *Beech Oven, Marra Forni, Zesti*

			
Plancha/Teppan Griddle *Jade, Montague, Vulcan, Woodstone, Adventys (Equipex)*	**Rack Ovens** *Baxter, Doyon, LBC Bakery, Revent*	**Heavy Duty Induction Ranges** *Cooktek, Lang, Vollrath, Garland*	**Hot Plate Ranges** *Imperial, Wells*

			
Electric Resistance Ranges *Garland, Imperial, Lang, Vulcan*	**Induction Ranges for Service/Buffet** *Cooktek, Garland, Hesten, Montague, Spring, Vollrath, Adventys (Equipex)*	**Stock Pot Ranges** *Garland, Imperial*	**Rotisseries** *Alto Shaam, Henny Penny, LBC, Rotisol*

			
Salamanders *Garland, Imperial, Vulcan, Hatco, Sodir (Equipex)*	**Smokers** *Alto Shaam, Cookshack, Nu-vu*	**Steamers** *Cleveland, Groen, Hobart, Vulcan*	**Tandoor Oven** *Beech*

		
Induction Warming Table/Buffet *Bon Chef, Cooktek, Garland, Hatco, Rosseto, Spring USA, Vollrath*	**Induction Countertop Woks** *APW, Cooktek, Garland, Imperial, Spring USA, Vollrath*	**Induction Drop-In Woks** *Cooktek, Electrolux, Equipex, Garland, Vollrath*

Induction Ranges

Southbend	Garland	Lang	Fisher & Paykel	AGA	Bertazoni
					

Single Burner Countertop Induction Cooktops

Manufacturer and Product Image	**Update** International IC 	**Eurodib** C1813 	**Waring** WIH200 	**ChangBERT** 	**Vollrath** 6950020 	**Breville** The Control Freak 
Price	$200	$90	$150	$250	$610	$1,499.95
Temp. Range	140°F-460°F	150°F-450°F	Up to 450°F	NA	NA	77°F -482°F

Two Burner Countertop Induction Cooktops

Manufacturer and Product Image	**Cooktek** 	**Hatco** 	**Waring** 	**Volltrath** 

Four or more Burner Counter Top Induction

	Vollrath 	Cooktek – 6 burner induction 	Viking 

Commercial Electric Ranges

Manufacturer and Product Image	**Bertazzoni** PRO304INMXE 	**Garland** SS686 	**Vulcan** EV36S4FP1HT2 	**AGA Elise** AEL48IN-SS 	**Lang** R36C-APA 	**Garland** SS684 
Price	$3,000	$6,490	$8,440	$7,050	$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	7" (2x)/ 5"/ 8"	6 ½" (x3)/ 8 ½" (x3)	NA	Flattop	24" griddle/8"	NA

Commercial Ovens (208V)

Manufacturer and Product Image	**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 Electric Griddles

Product	**APW Wyott** EG-24S 	**Avantco** EG30N 30" 	**Cecilware Pro** EL1636 	**Garland** 36ER38 36" 
Temp Range (Degrees F)	150-450	150 - 570	N/A	100-450
Frequency (Hertz)	60	60	60	60
Voltage (V)	208/240	208/240	240	208/240
Max Power Consumption (W)	9,000	4,500	3,600	21,500
Oven Included	No	No	No	Yes
Price (USD)	$1,430	$479.99	$912.45	$10,218

Electric Induction Woks (240V / 15A)

Manufacturer and Product Image	**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

Manufacturer and Product Image	**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 / Buffet Equipment

Manufacturer and Product Image	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

Rapid Cook Pizza Oven

Manufacturer and Product Image	TurboChef 	MerryChef 	TurboChef 	Vollrath 
Amp/ wattage	800-900 watts	30amps / 6200 watts	3700-4800 watts	15amps/ 3600 watts
Volts	208/240 v	208/240	208/240	240
dimensions	16/25/21 inches	28/27/23	19/18/21	28/26/21
Price	$6,162	7,663	$5884	1,141

Food Steamers

Electric Food Steamers	Cleveland 	Cleveland 	Vulcan 	Cleveland 
Voltage	240	208 3 phases	208	240 3 phase
Amps	59.5	29.8	94 amps	79.8 amps
Wattage	14.28 Kw	10.725 kw	30 kilowatts	32.6 Kilowatts
Capacity	6 pans	12 pans	10 pans	10 pans
Dimensions	21x 32 x 30 inches	25 x 36 x 67 inches	24 x 35 x 71 x inches	24 x 33 x 65 inches
Price	$ 9,970	$ 21,699	$ 18, 752	$ 20,246

Electric Coffee Roasters

Bellwether Coffee	Toper
	

Residential

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. Gas stoves cause unhealthy levels of Nitrous Oxides that would be illegal if it were from a gas power plant. After just twenty 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 [116]stoves. 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.

Consumer Reports Prefers Induction

Top 6 of 8 Ranges for 2020 were electric, top 2 were Induction

Fuel	Model	Consumer Reports Rating	Cost
Induction	GE Profile PHS930SLSS	86	$2,432
Induction	Kenmore Elite 95073	84	$1,525
Gas	LG Signature LUTD4919SN	84	$3,000
Induction	LG LSE4617ST	82	$2,500
Induction	LG LSE4616ST	82	$1,700
Smoothtop	Whirlpool WGE745c0FS	82	$1,000
Gas	Samsung NY58J9850WS	81	$2,725
Induction	Frigidaire Gallery FGIF3036TF	81	$1,035

Figure 35: Consumer Reports prefer induction, the top 6 of 8 ranges for 2020 were induction.

Glass Top Radiant Range ($550 or less)

Manufacturer and Product Image	**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)

Manufacturer and Product Image	**Samsung** NE59M4310SS/AA 	**GE** JB480DMBB 	**LG** LSSE3026ST 	**Bosch** 800 Series 
Max Power (Watts)	9,600	10,500	13,500	14,800
Price	$700	$950	$1,800	$2,200
Oven Space (cu. ft)	5.9	5.0	6.3	4.6

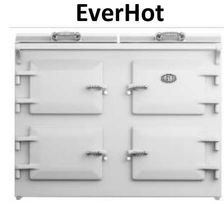
Slide-In Induction Range (Lowest Cost, 240V, 40 amp)

Manufacturer and Product Image	**Frigidaire** FFIF3054TS 	**LG** LSE4616ST 	**Frigidaire** Gallery FGIH3047VF 	**Samsung** Virtual Flame NE58K9560WS 	**GE** Profile PHS930SLSS 
Price	$1,000	$1,900* limited rebate from LG	$2,000	$2,400	$2,440

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

Manufacturer and Product Image	**KitchenAid** KSIB900ESS 	**Bosch** HII8056U 	**Café** CHS900P2MS1 	**Bertazzoni** Professional PROF304INSROT 	**Fisher & Paykel** Series 9 OR36SCI6R1 
Price	$2,970	$3,400	$3,420	$4,990	$7499 (50 amp)

Residential 48” Induction Range

Manufacturer and Product Image	**AGA Elise** 	**AGA Mercury** 	**EverHot** 
Price	$7,049	$7,049	$13,319 (£9,530.00)
Range Width	47 9/16th inch	47 9/16th inch	-
Total Width	48	48	47.2
Number of Burners	5	5	5
Oven Wattage	2,500	2,500	

Retro Induction Ranges

Manufacturer and Product Image	**Smeg Range Cooker Victoria** TR4110IPG 	**Retro Collection** BCRI30 	**Elmira Northstar** 1954P 	**Ilve Majestic II Collection** UMDI10NS3MBP 	**AGA Classic** ATC3 
Price	$3,500	$5,100	$5,800	$9,100	$22,000
Max Power (W)	8,400	2,500	2,500	12,000	9,600

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

Manufacturer and Product Image	**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

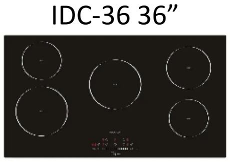
Single Burner Drop-In Induction (1800W, 120V and using a 15amp circuit)

Manufacturer and Product Image	**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 and Triple Burner Countertop Induction (1800W, 120V and using a 15amp circuit)

Manufacturer and Product Image	**Eurodib** S2F1 	**True Induction** TI-3B 	**NuWave** PIC Double 	**Inducto** 	**Duxtop** 9620LS 
Price	$200	$525	$200	$150	$190
Temp. Range	150°F -450°F	140°F -460°F *(Three Burners!)*	100°F – 575°F	176°F -460°F	140°F -460°F

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

Manufacturer and Product Image	**Empava** IDC-36 36” 	**Bosch** NETP068SUC 30” 	**Samsung** NZ36K7880UG 36” 	**Frigidaire** FPIC3677RF 36" 	**Elica** ENS436BL 36” 
Price	$900	$1,300	$2,300	$2,500	$4,410

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 lose 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 Usage Monitor.

Insulating your cookware saves energy by dramatically reducing heat loss during cooking. This study concluded that the ideal cookware to reduce energy consumption 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.

Manufacturer and Product Image	**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.*

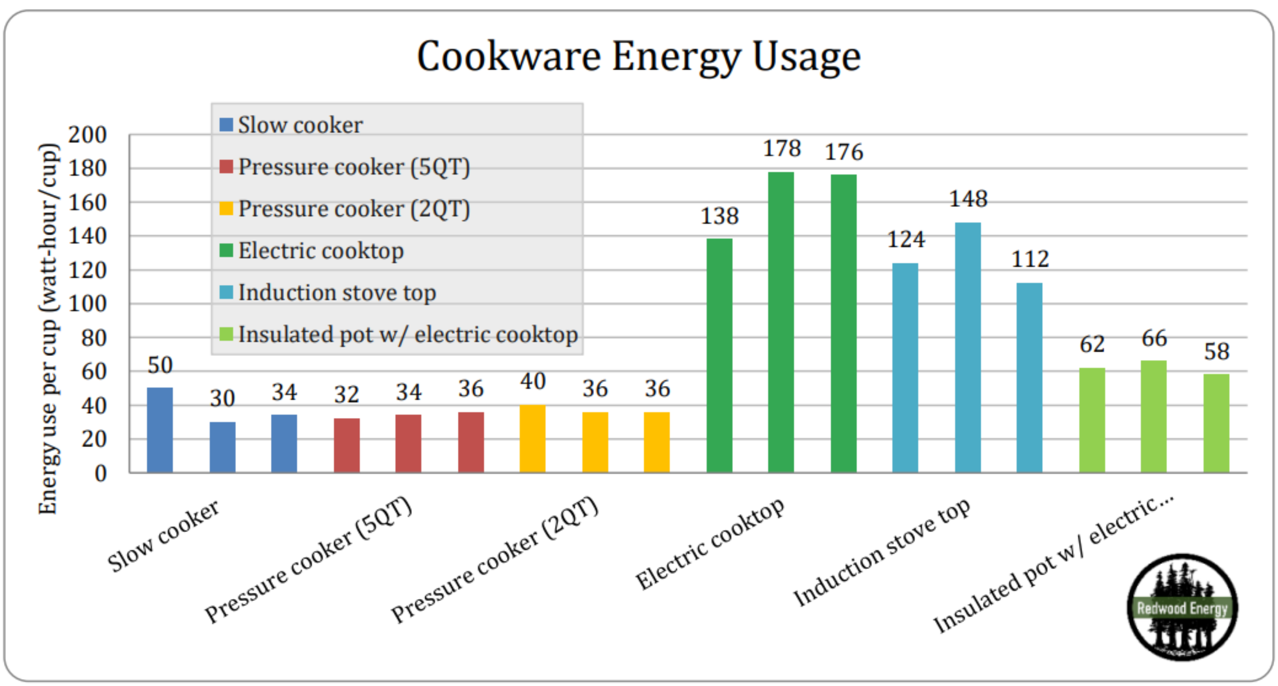


Figure 36: The results of the low power cooking study, the lowest energy use per cup were the pressure cooker and slow cookers.

Countertop Ovens (120V)

Are you looking it 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.

Manufacturer and Product Image	**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 door design allows for single door to be opened when checking on food. Dials or digital touch interface.

Manufacturer and Product Image	**Black and Decker** Toaster Oven 	**KitchenAid** Dual Convection Countertop Oven 	**Breville** BOV900BSS Smart Oven Air 	**Hamilton Beach** Convection Oven 
Oven Size (ft^3)	1.1	1	1	-
Dimensions (DxWxH) (in)	21.5 x 14.5 x 11.2	16.4 x 18.5 x 13.0	17.5 x 21.5 x 12.7	20.6 x 16.5 x 13.1
Power (W)	1500	1800	1800	1500
Price	$105	$280	$400	$130
Remarks	Airfry setting Can fit a 9"x 13" pan	Built in temperature probe "Can bake 2 whole chickens (based on 3.6 lb. weight)	14 lb. turkey, LCD display, 6 independent heating elements, 13 cooking functions	Rotisserie, convection

Kitchen Hoods (Low Sound, High Air Flow)

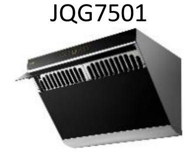
To evacuate pollution from cooking properly, a quiet yet high air flow kitchen hood is essential. The effectiveness of kitchen hoods is so important that California is instituting a new policy in their building energy code - kitchen hoods for electric stoves must have a flow rate of 110 to 160 cfm and gas stoves must have a flow rate of 180 to 280 cfm, depending on the size of the unit. Venting pollution from gas cooking requires a higher flow rate because gas creates more pollutants when burned (like NO2, which is regulated by the EPA to maintain high outdoor air quality). The kitchen hood must also be at a sound level of 3 sones or less, so residents can use them comfortably. The following kitchen hoods meet this requirement in California, and are considered products for best practices for efficient, comfortable, and all-electric buildings.

Proposed minimum range hood capture efficiency (CE) requirements, and proposed alternative airflow compliance requirements for demand-controlled range hoods

Dwelling Unit Floor Area (ft^2)	Hood Over Electric Range	Hood Over Natural Gas Range
>1500	50% CE or 110 cfm	70% CE or 180 cfm
1000 - 1500	50% CE or 110 cfm	80% CE or 250 cfm
750 - 1000	55% CE or 130 cfm	85% CE or 280 cfm
<750	65% CE or 160 cfm	85% CE or 280 cfm

Or
Downdraft exhaust with minimum of 300 cfm (no change from 2019 requirements)
Or
Continuous exhaust at 5 kitchen ACH50 (applies to enclosed kitchens only – no change from 2019 requirements)

Quiet Kitchen Hoods

Manufacturer and Product Image	**ProLine** PLJW 125 series 	**Zephyr Power** Typhoon Series AK2100BS 	**KOBE** Brillia CHX91 SQB-1 	**KOBE** Premium RA38 SQB-1 	**FOTILE** JQG7501 
Noise (sones)	1.5 @ 385 CFM 7.5 @ 900 CFM	2.5 @ 300 CFM	3 @ 300 CFM	3 @ 300 CFM	2.64 @ 510 CFM
Air Flow (CFM)	900	850	680	680	850
Width (inches)	30, 36	30, 36, 42, 48	30, 36	30, 36	30
Cost ($)	$719 (30 in) $740 (36 in)	$679 (30 in) $629 - $709 (36 in)	$593 (30 in) $600 (36 in)	$539 (30 in) $575 (36 in)	$1,099.00

Quiet Low-Cost Hoods Compliant with 2022 Code

Manufacturer and Product Image	**Broan** QS136AA 	**Broan** RP136WW 	**Broan** 	**Whirlpool** WVU57UC0FS 	**KitchenAid** KVUB400GSS 30" 	**BV** Range Hood 
Noise (sones)	5.0 @ 210 CFM 5.0 @ 220 CFM 5.0 @ 230 CFM	0.5 @ 120 CFM* 7.0 @ 440 CFM	1.2 @150 CFM 3.0 @ 200 CFM 5.5 @ 280 CFM	0.5 @ low speed 5.2 @ 350 CFM	0.1 @ low speed 5.2 @ 400 CFM	1.5 @ 200 CFM 7.5 @ 750 CFM
Air Flow (CFM)	210/230 vertical, 220 horizontal	440	300	350	400	750
Width (inches)	36"	36"	30”	30"	30"	30"
Exhaust Method	Ducted & Ductless	Ducted	Ducted & Ductless	Ducted & Ductless	Ducted & Ductless	Ducted
Cost	$85	$170	$200	$220	$365	$340

*compliant airflow for a dwelling unit of 1500 ft^2 or less floor area

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 consumption is convenience—households with in-unit laundry run twice as many loads as households with only access to a central laundromat.[117] 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,[118] assuming one is using a standard ~30% efficient gas dryer, rather than a ~250% efficient electric heat pump dryer.

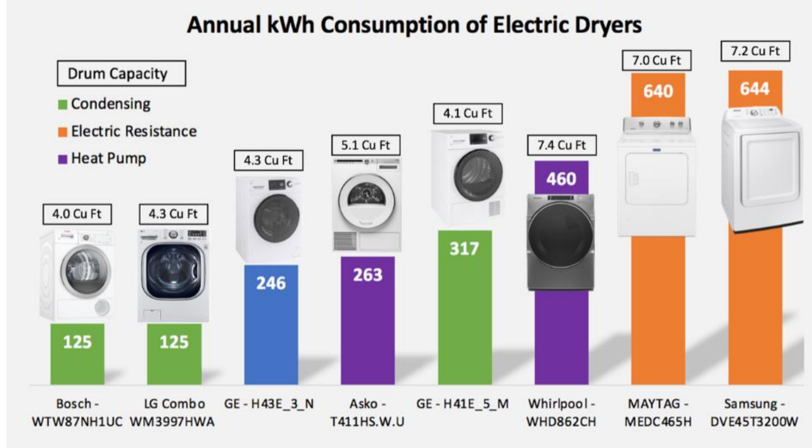


Figure 37: Relative dryer energy use, condensing dryers and heat pump dryers use roughly half the energy of a standard electric resistance dryer.

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[119]. 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.[120]

Condensing Washer & Dryer—**A combined appliance**

Condensing Washer/Dryers 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 2-4 hours, depending on the fabric and load size.

"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 combined washer/dryer user***

Combination Condensing Washer & Dryer (120V)

Manufacturer and Product Image	**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)

Manufacturer and Product Image	**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)

Manufacturer and Product Image	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

In California, the greatest percentage of smog and greenhouse gas emissions in the state come from fuel burning vehicles. Electric vehicles create no direct air pollution, rely on a grid in California that is 50% renewables, 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 2022 model electric vehicles with their specifications, provided by Menlo Spark.[3] For inspiration is also an example of a 1946 pickup truck electrification.

Manufacturer	Audi	BMW	BMW	Chevrolet	Chevrolet	Ford
Model	e-tron	i4	iX Drive 50	Bolt EV	Bolt EUV	F-150 Lightning
Passengers	5	5	5	5	5	4
Doors	5	5	5	5	5	2
MSRP (from) [1]	$43,900	$55,400	$83,200	$37,495	$37,495	$52,974
Federal Tax Credit [2]	$7,500	$7,500	$7,500	N/A	N/A	$7,500
Car Body	Hatchback/SUV	Coupe	SUV	Hatchback	Hatchback	Truck
EPA Range (miles)	241	270	324	259	247	230
MPGe City / Highway	100/89			257/309	270/324	
MPGe Combined	95			281	293	
Battery Capacity (from)	82 kWh	83.9 kWh	111.5 kWh	65 kWh	66 kWh	98 kWh
Horsepower	295	170	181	200	200	563
0-60 Speed	7.9 seconds	5.5 seconds	4.4 seconds	6.5 seconds	7 seconds	4.5 seconds
Charge Time (240 volt)	7.5 hours	11-15 hours	9-12 hours	7 hours	7 hours	
DC Fast Charge Time [3]	5%-80% in 38 min	80% in 31 min	80% in 35 min	100 miles in 30 min	100 miles in 30 min	15%-80% in 1:31
Max Cargo	53.1 cu ft	45.56 cu ft	61.8 cu ft	56.9 cu ft	57 cu ft	52.8 cu ft
Additional Notes						production to start in Spring 2022 on 2023 model

Manufacturer	Hyundai	Hyundai	Jaguar	Kia	Kia	Lucid
Model	Ioniq EV	Kona Electric	I-Pace S	Niro EV	EV6	Air Grand Touring
Passengers	5	5	5	5	5	5
Doors	4	4	5	4	4	4
MSRP (from) [1]	$39,700	$34,000	$69,900	$40,900	$39,990	$139,000
Federal Tax Credit [2]	N/A	$7,500	$7,500	$7,500	$7,500	???
Car Body	Hatchback	SUV	SUV	Crossover	SUV	Sedan
EPA Range (miles)	220	258	234	239	232	469
MPGe City / Highway	132/98	132/108	80/72	136/100	123/102	121/122
MPGe Combined	114	120	76	117	112	121
Battery Capacity (from)	58.2 kWh	64 kWh	90 kWh	58kWh	64 kWh	112 kWh
Horsepower	139	195	197			
0-60 Speed	5	7.9	4.5 seconds	7.5 seconds	8 seconds	3.0 seconds
Charge Time (240 volt)	6 hours, 5 minutes	6 hours, 10 minutes	13 hours	9 hours	7.5 hours	
DC Fast Charge Time [3]	80% in 54 min	80% in 54 min	80% in 45 - 85 minutes	80% in <1 hour	80% in <1 hour	
Max Cargo	56.2 cu ft	39.3 cu ft	25.3 cu ft	49.6 cu ft	45.9 cu ft	
Additional Notes			2020 model			

[3] Go to www.menlospark.org to learn more.

Manufacturer	Mercedes Benz	Mini	Nissan	Nissan	Polestar	Porsche
Model	EQS	Cooper SE	Leaf S	Leaf e+ S	Polestar 2	Taycan
Passengers	5	4	5	5	5	4
Doors	4	2	4	4	5	4
MSRP (from) [1]	$102,310	$29,900	$29,900	$36,550	$45,900	$82,700
Federal Tax Credit [2]	$7,500	$7,500	$7,500	$7,500	$7,500	$7,500
Car Body	SUV	Hatchback	Hatchback	Hatchback	Sedan	Sedan
EPA Range (miles)	340	114	149	226	270	200
MPGe City / Highway	92/99	119/100	123/99	118/97		76/84
MPGe Combined	95	110	111	108		79
Battery Capacity (from)	115 kWh	32.6 kWh	40 kWh	62 kWh	100 kWh	79.2 kWh
Horsepower	329	181	147	215		
0-60 Speed	5.9 seconds	6.9 seconds	7.4 seconds		7 seconds	5.1 seconds
Charge Time (240 volt)	8 hours	4.25 hours	8 hours	10 hours	7 hours	
DC Fast Charge Time [3]	80% in 23 minutes	80% in 39 min	80% in 40 min	80% in 43 min	80% in 31 min	
Max Cargo	62.5 cu ft	7.45 cu ft	30 cu ft	30 cu ft	14.27 cu ft	14.37 cu ft
Additional Notes						other models with higher range/power

Manufacturer	Rivian	Tesla	Tesla	Tesla	Tesla	Volkswagen	Volvo
Model	R1T	Model S	Model X	Model 3	Model Y	ID.4 Pro	C40 Recharge
Passengers	4	5	5 to 7	5	5 to 7	5	5
Doors	5 or 7	4	4	4	4	5	
MSRP (from) [1]	$67,500	$94,990	$104,990	$44,990	$58,990	$40,760	$58,750
Federal Tax Credit [2]	$7,500	N/A	N/A	N/A	N/A	$7,500	$7,500
Car Body	Truck	Sedan	SUV	Sedan	SUV	SUV	SUV
EPA Range (miles)	314	405	348	272	330	260	226
MPGe City / Highway	74/66	124/115	107/97	138/126	127/117		94/80
MPGe Combined	70	120	102	132	122		87
Battery Capacity (from)	135 kWh	100 kWh	100kWh	60 kWh	80 kWh	82 kWh	80 kWh
Horsepower		518	502.9+258.8	283			
0-60 Speed	3 seconds	3.1 seconds	3.8 seconds	5.8 seconds	4.8 seconds	7.7 seconds	4.7 seconds
Charge Time (240 volt)		8.75 hours	5.75 - 8.75 hours	5.75 hours			
DC Fast Charge Time [3]	80% in 41 min	80% in 40 min at Supercharger	80% in 50 min at Supercharger	80% in 30 min at Supercharger			
Max Cargo	11.65 cu ft	58.1 cu ft	81.21 cu ft	12 cu ft	66 cu ft	55.6 cu ft	
Additional Notes		other models with higher ranges	other models with higher ranges	other models with higher ranges	other models with higher ranges		

EVs and Outdoor Recreation Inspiration

Gas to EV Conversions

Story from Amy Dryden of Franklin Energy

"Commuting by bike in Oakland and inhaling the exhaust of a 1950s Chevy made it crystal 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—plenty enough. The Motor went from 400lb flat V-8 engine with 160lbs of fuel, 560lbs total, to a 60lb motor with 300lbs of batteries—360lbs, 200lbs 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 38: Electrified 1946 Fork Pickup truck.[121]

Electric Cargo Bikes

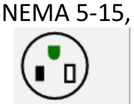
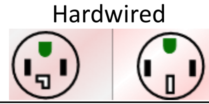
The first cargo bikes were human powered and constructed specifically to transport loads by tradesmen delivering mail, bread, milk, and other goods. Today, electric cargo bikes integrate an electric motor which assists the rider with propulsion and operate like hybrid vehicles, where the electric motor combines battery propulsion with pedal power instead of internal combustion engine power. By emitting no CO2, replacing car trips with E-cargo bike rides helps reduce CO2 emissions. Batteries are rechargeable and can travel up to 15-25 mph on average. The design includes cargo areas in the front, back, or sides of the bike. Many models include not only cargo areas for the transport of goods, but leash hookups for pets and seating with seat belts for children. The popularity of E-cargo bikes is on the rise and growth is projected to be exponential in the next few years as the reserves of crude oil declines leading to a high demand of vehicles that run on alternative energy. According to Persistence Market Research, "The global electric cargo bikes market is estimated to be valued at US$ 402.7 Mn by the end of 2018 and reach US$ 1,095.2 Mn by the end of 2026."

				
Name	**Radwagon 4 – Rad Power Bikes**	**The Original – Bunch Bikes**	**The Coupe – Bunch Bikes**	**The K9 – Bunch Bikes**
Payload Capacity	350 lb	350 lb	350 lb	350 lb
Battery	48V 14Ah	48V 13.6Ah	36V 20Ah	48V 13.6Ah
Motor	750W	500W	250W	500W
Range	25-45+ miles per charge	25-35 miles per charge	Up to 75 miles per charge	25-35 miles per charge
Charge Time	3-7 Hours	4-6 Hours	2-3 Hours	4-6 Hours
Max Speed	20 mph	15-20 mph	20 mph	15-20 mph
Price	$1,699	$4,499	$5,999	$4,699

				
Name	**The Preschool – Bunch Bikes**	**GSD S00 - Tern Bicycles**	**Cargo XL – Urban Arrow**	**E- classic X2s -Xtracycle**
Payload Capacity	350 lb	440 lb	418-606 lb	400 lb
Battery	48V 13.6Ah	Single 500 Wh or Dual 1000 Wh	400Wh – 500 Wh	1000Wh (Two dual 500Wh packs)
Motor	500W	36V/250W	250W	250 W
Range	25-35 miles per charge	500Wh 32-62 miles 1000Wh 620125 miles	20-40 miles per charge	50-100 miles per charge
Charge Time	4-6 Hours	4.5 Hours	3-4 hours	4-5 hours
Max Speed	15-20 mph	20 mph	15 mph	28 mph
Price	$4,999	500Wh - $4,999 1000Wh - $5,799	$6,699	$6,414.50
				
Name	**Electric Supermarche - Yuba**	**Packa - Blix**	**Payload - Magnum**	**XP Step-Thru – Letric**
Payload Capacity	300 lb	400 lb	350 lb	330 lb
Battery	36V	1171 Wh	46V 13Ah	48V 10.4Ah
Motor	250V	750W	500W	500W
Range	20-55 miles per charge	70 miles per charge	25-55 miles per charge	45+ miles per charge
Charge Time	4.5 Hours	5 Hours	6 Hours	4-6 Hours
Max Speed	20 mph	20 mph	20-25 mph	20 mph
Price	$5,500	$1,599	$2,499	$899

Electric Vehicle Supply Equipment (EVSE)

EV Charging standards have been developed under the EVSE protocol. There are three levels, Level 1, Level 2, and Level 3 (aka DC Fast Charging). These levels are associated with how much power can be delivered to your car. The EV charger can be connected to the grid via a hardwired connection to an electrical panel, done by an electrician, or a NEMA (National Electrical Manufacturer's Association) standardized outlet. For Level 1 this will be the standard 120-volt and 15 to 20-amp socket found on your kitchen counter, bathroom, or bedroom outlet. For Level 2 chargers, depending on the power requirement you may see a typical 30-amp electric clothes dryer outlet, also called NEMA 14-30, or a typical 50-amp electric oven outlet, called NEMA 14-50; or else the charger may be hardwired by an electrician. DC Fast Chargers use DC power, as opposed to AC power coming from the grid, to charge the battery of your car. Level 3 chargers are almost never found in single-family homes, due to the amount of power needed.

	Level 1[122]	**Level 2**[123]	**Level 3**
			
Electrical Specifications	120 Volts, 15 to 20 Amps maximum	240 Volts, 20 to 40 Amps, 30 Amps is common	DC Fast Charging, 12kW or greater
Grid Connection, NEMA Receptacle	NEMA 5-15, NEMA 5-20 	NEMA 14-30, NEMA 14-50, Hardwired 	Always Hardwired, very rare outside of Multifamily and Commercial applications
Connector Types	SAE J1772 aka CCS	SAE J1772 aka CCS	CHAdeMO, SAE J1772 aka CCS + 2 pins, Tesla proprietary

EVSE Level 2 EV Chargers

	SolarEdge LJ40P-KIT-SA-EV-S	**Juicebox**[124] JuiceBox 40	**Chargepoint**[125] ChargePoint Home Flex	**Siemens** VersiCharge
				
Connector	SAE J1772	SAE J1772	SAE J1772	SAE J1772
NEMA Types[126]	NEMA 6-50	Hardwired or Plug (NEMA14-50P)	Hardwired or Plug (NEMA 6-50 or 14-50)	Hardwired or Plug (NEMA 6-50)
Output Amps	40	40	50	30
Output Power (kW)	Up to 9.6	Up to 9.6	3.8 - 12	1.8 - 7.2
Mounting Method	Wall-mounted	Wall, Column, or Pedestal	Wall, Column, or Pedestal	Wall-mounted
Input Amps (240V)	40A	40A	50A	32
Breaker Size (Amps)	50, 2-phase	50, 2-pole	50, 2-pole	40, 2-pole
Input Voltage	240 AC	208-240 VAC, 1-phase	208-240 VAC, 1-phase	208-240 VAC
Input Power	-	10,000W	10,000W	7,700W
Price	$550	$599 (base)	$699	$730

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 utility 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,[127] 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 utility 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.[128]

Available Soon in the United States

	Wallbox[129] Quasar 	**Ossiaco[130]** dcbel 	**Nuvve[131]** PowerPort 	**Fermata Energy[132]**
Vehicle-to-Home	X	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 for commercial use	• Commercial and residential capabilities • Coming to the US market in 2021

Not Available in the United States

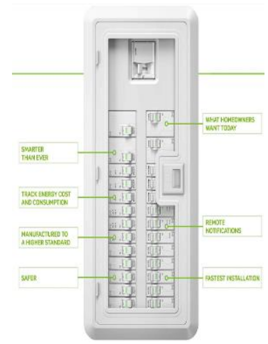
A plethora of companies outside the United States have V2H and V2G chargers, demonstrating that the market is ready for this technology. Using a car's battery to power your home or to give back to the grid will be an essential service in our all-electric future.

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

Energy Management Systems

This section focuses on products that can 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, the restarting EV charging. Other products allow scheduling loads, connecting with solar PV, and home battery charging optimization, among many other features. See above for the Ossiaco product.

Whole House Panels

	Span[133] 	**Eaton**[134] Pow-R-Command 	**Koben**[135] GENIUS Smart Panel 	**Koben** Genius Smart Panel 	**Leviton** Smart Load Center 
Cost	$2,500 including installation costs	TBA	$3,495	$5,545	TBA
Size	100-200 A	120/240 V System (1A) and 480/277 V System (2A)	Up to 200A at 240Vac, up to 200A at 120Vac (including one additional source of 100A), Up to 240A per phase for 3 phase	Up to 500A at 240Vac, Up to 250A at 120Vac (including one additional source of 100A), Up to 200A per phase for 3 phase	100A to 225 A Loads
Number of Circuits	-	Can add expansion panels up to 168 controllable circuit breakers	UP to 18 circuits	UP to 24 circuits	20 to 66 circuits
Max Amps	225A bussing (whole panel)	Continuous Current Rating 100-600 A (whole panel)	maximum of 50A continuous (circuits)	maximum of 50A continuous to support 60A breaker	-
Solar	4 KW system	-	Yes	Yes	-
Description	Plug in play solution for rooftop solar, battery storage and EV charging	Designed to optimize power distribution systems by decreasing electrical equipment footprint and consolidating protection devices within a single enclosure	Can integrate EV Charging, Solar, Battery Storage, Generator, and your utility whether you are planning for the new energy era or have already installed your new energy technology	Can integrate EV Charging, Solar, Battery Storage, Generator, and your utility whether you are planning for the new energy era or have already installed your new energy technology	-

Subpanels

Eaton[136] Energy Management Circuit Breaker (EMCB) 	• Programmable breakers to prioritize loads in power outage 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**[137] Smart Panel 	• Real time balancing of battery use and EV 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
Available for purchase		**$2,500 – 4,000 Single Family home Install**	

Smart Circuit Splitters (EV Charging and Appliances)

There are a few types of smart circuit splitters shown in the table below. Smart circuit breakers allow two devices (typically high power) to share a circuit, which can avoid an electrical panel upgrade (For example, like an EV charger and a Dryer). A more sophisticated version of this (DCC and EVduty) will actually monitor the whole home's power consumption then adjust EV charging accordingly. The Neo Charge and the Dryer Buddy both come with built in plugs for attaching to the wall and two appliances, so they are easy to install. Both products also have two options for power sharing – the first, power is supplied to one device or another, and the second, power is supplied to two devices simultaneously. The SimpleSwitch is typically hardwired and just has the first option of powering one device at a time. The Thermolec DCC products and the EVduty will both monitor a whole homes power consumption – however the DCC products will turn EV charging off when the load on the home panel exceeds 80% of its rated capacity, versus the EVduty that will determine the left-over power space on the panel, then supply this to the EV for continuous charging.

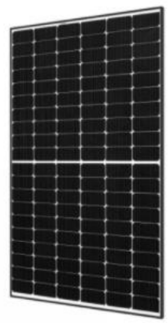
(more on the next page)

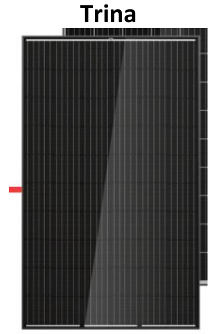
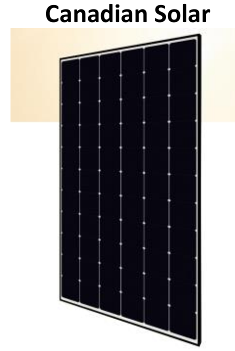
	SimpleSwitch[138] 240MEV Circuit Switch 
Cost ($)	TBA
Switch On/Off Between Two Devices	Yes
Continuous Power to Two Devices	Yes, when total demand of panel is below 80% capacity
Monitors Whole House Loads	yes
NEMA Outlet ***(NEMA-Amps)***	Hardwired (Level 2 charger: NEMA 14-30, 14-50, 10-30, 10-50, 6-50)
Additional Notes	SimpleSwitch 240MEV changes the charging current to the EV in real-time in response to the apartment/condo's varying loads. The main circuit breaker's total power consumption does not exceed 80% of the full allowable load. SimpleSwitch 240MEV will only allow power to be delivered to the EV charger if the total demand of the panel is below its 80% capacity.

	Neo Charge[139] Smart Splitter 	**BSA Electronics**[140] Dryer Buddy 	**SimpleSwitch**[141] 240V Circuit Switch 	**Splitvolt**[142] Splitter Switch 	**Thermolec**[143] DCC 	**EVduty**[144] Smart Current Sensor 
Cost ($)	$500 (Appliance) $550 (Dual Car)	$200 – 365 (several outlet versions)	$649 (240V) $729 (EV) $550 (120V)	$319	$1,050 (DCC-9), $945 (DCC-10)	$500
Switch On/Off Between Two Devices	Yes	Yes	Yes	Yes	NA	NA
Continuous Power to Two Devices	Yes	Yes	No	No	NA	Yes, *shares power between appliance circuit and EV circuit*
Monitors Whole House Loads	No	No	No	No	Yes, *if total panel exceeds 80% rated load, turns off EV charging. Reconnects automatically*	Yes, *monitors a unit/home's current draw, left over current will be used to charge EV*
NEMA Outlet *(NEMA-Amps)*	*10-30, 14-30, 14-50, (10-50 for portable))*	*10-30 to 10-30, 10-30 to 14-50, 14-30 to 14-30)*	Hardwired, Optional Plugin	*10-30, 14-30, 14-50*	Hardwired	Hardwired, or NEMA 6-50, 14-50 outlet
Additional Notes		digital display that shows the draw of each load.	120V version as well	Full color display screen	Multifamily and Single Family, DCC-10 uses one double pole breaker slot	Multifamily and Single Family.

Solar Photovoltaic Panels

The cost of installing solar on a home depends on the amount of electricity a homeowner wants to generate. In addition, the state you are in, how much energy you use, your roof's sunlight exposure and complexity, panel manufacturer, and size of the system all contribute to the costs of a solar array. 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. There is a 22% tax credit from the Federal Government on installing solar in homes in the year 2021 and by the year 2022 there will only be available tax credit of 10% to commercial buildings. About 47% of the cost of solar systems is solar equipment, 35% of cost on installation and permits, and 18% of cost is operation and maintenance. Below are some of the leading manufacturers of solar panels with their associated cost from August 2020. Unshaded good exposure solar arrays produce power that ends up costing only 6-8 cents per kWh over the life of the system. It pays to own the system and to maximize the power output by going **large** and **efficient** to decrease the amount of grid power you need to buy. Think of solar panels as the way to make electrification extremely cost effective and saving hundreds of dollars over the course of the solar array's lifetime.

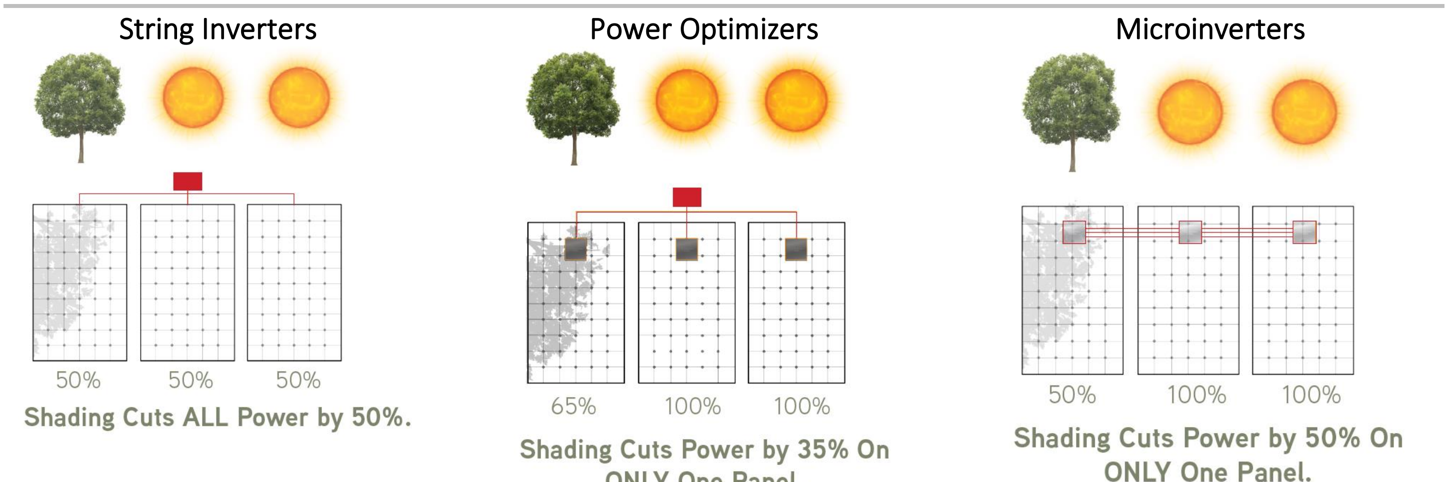
	SunPower Maxeon® Gen5	**Q Cells** Q. Peak DUO ML-G9	**REC** Alpha	**LG** Neon 2	**Winaico** WSP-340MX
					
Type	Monocrystalline	Monocrystalline	Monocrystalline	Monocrystalline	Monocrystalline
Power Output (W)	400	390	370	345	340
Efficiency	22.3%	20.8%	21.2%	20.1%	19.4%
Size (in) (LxWxD)	Contact	72.4 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 ($)	SunPower	$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

Solar Inverters and Solar Array Sizing

Figure 39: A typical 1,200 sq. ft. and 2,000 sq. ft. home. Illustration by Isabella Barrios Silva.

Solar inverters are one of the most important parts of a solar panel system - they take energy from solar panels and convert it from DC power to AC power to use within a building. To offset the average energy use of a typical 1,200 square foot house, the solar array will be about 200 square feet and 4 kW of DC power. For an average 2,000 square foot house, the solar array will be about 400 square feet and about 8 kW of DC power. Each panel is about 20 square feet and about 400 Watts per panel. To power an average electric car for a year (12,000 miles), it requires an additional 2 kW solar array using 100 square feet of roof space.



Illustrations by Isabella Barrios Silvia

Solar string inverters use **one central inverter** connected to all solar panels in a **single circuit,** such that one panel's shading affects the power produced by all panels. The circuit may have multiple wired ("strings") connecting the panels.

Advantages: lower installation and maintenance costs

Disadvantages: warranty will be shorter (10-12 years) compared to micro-inverters (25-year warranty).

A solar array with power optimizers has **one central circuit / inverter making** wiring easier to install, and **multiple system optimizers** on each solar panel allows **each panel to provide maximum power** without being affected by other panels negatively.

Advantages: similar advantages as micro-inverters but at a lower cost and have a 20–25-year warranty.

Disadvantages: higher maintenance costs since they are exposed to the environment on the roof. Central inverters only have a 10-12-year warranty.

Microinverters are an **individual inverter and circuit on each solar panel,** allowing them to operate independently to provide maximum power and to **not be negatively affected by other panels.**

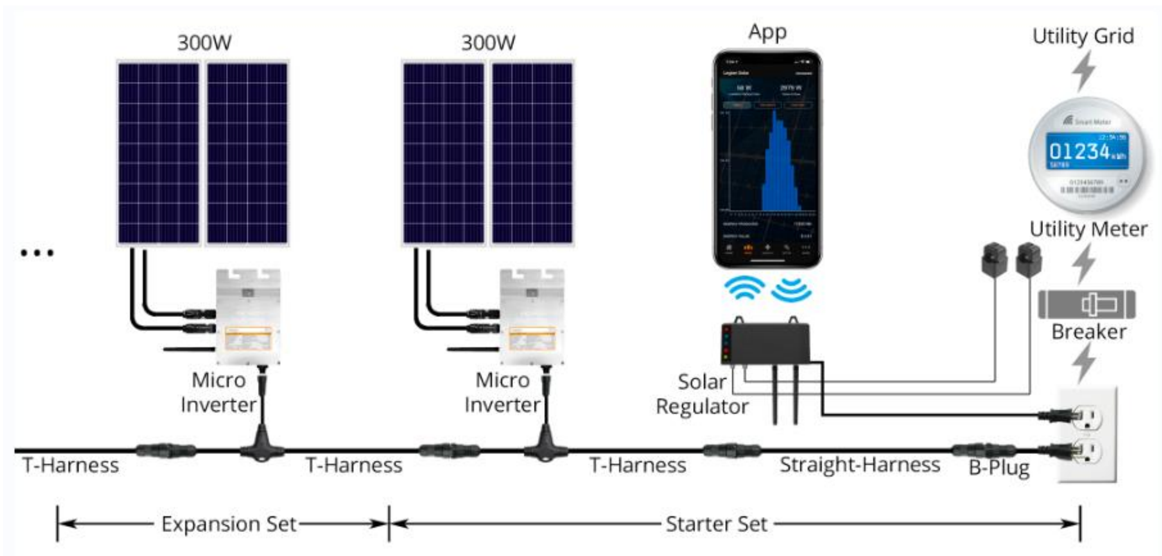
Advantages: can track production of each panel individually, making it easier to detect if panels need maintenance.

Disadvantages: more hardware the on roof requires more maintenance compared to a string inverter.

Solar Array Size and the Watt Diet

The size of your electrical panel will cap the size of your solar array – because the code limits the maximum solar circuit to 20% of the size of the panel, a 100 Amp electric panel is limited to 20-amp solar circuits. Because long duration loaded circuits cannot be loaded to their maximum for safety reasons, this means only 16-amps are available (the "80%" rule). A typical solar array for a home is 240 volts, so this multiplied by 16-amps gives you a 3.8 kW max of AC power. However, most inverters allow for "clipping" which means you can install a solar array that is larger than 3.8 kW DC. Each inverter company allows a different "inverter load ratio" or how much an inverter can be overloaded. For the state-of-the-art Solar Edge and Enphase inverters, this ratio is 1.6, meaning you can have a max solar array DC size of 6.0 kWdc. When the solar array is producing more than the 3.8 kW AC the inverter can process, the excess energy is "clipped". However, this allows for the max amount of energy allowed by the inverter for more hours of the day, instead of just at around noon. Using DC coupled battery storage can also mitigate clipping by moving excess energy into storage instead of clipping it. With today's low solar panel prices and comparatively higher grid power prices it often makes good sense to install solar panels up to the inverter's load ratio, which can result in a cost less than 8 cents per kWh.

SolarRegulator by Legion Solar



The grid-tied Solar System**,** A technology that enables you to contain generated energy behind your meter where the utility company does not own to allow you to generate your own electricity unrestricted. The system is scalable starting as small as 300W and can expand in stages of 300W depending on your budget and needs. Once your system is large enough to have excess energy to store during daylight, you can add expansion sets for nighttime consumption, this expansion set enables the solar panels to charge the batteries, solar panels to supply power to the micro inverters, and batteries to supply power to the micro inverters. No permit needed, plugs in the wall, solar alternative to a backup generator, and a bill saver.

Solar Edge – Combined EV Charger and Solar Inverter

Model	SE3800H-US	SE7600H-US
Maximum Ac Power Output (VA)	3,800 @ 240V	7,600 @ 240V
AC Output Voltage Range (Vac)	240	240
AC Frequency (Hz)	59.3-60-60.5	59.3-60-60.5
Max DC Charger Power (W)	9,600	
EV Charger Connector Type	SAE-J1772-2009, aka CCS	
Maximum DC Power (W)	5,900	11,800

Enphase - Microinverters

	Model	IQ7	IQ7X	IQ7	IQ7A
	Price ($)	147	175	155	179
	Max Output AC Power (VA)	295	320	250	366
	DC Input Power (W)	235 - 440	320 - 460	235 - 350	350 - 460
	Max DC input Voltage (V)	60	79.5	48	58

Solar Edge – Single Phase Inverters

	SE3800H-US	SE6000H-US	SE7600H-US	SE10000H-US	SE11400H-US
					
Maximum Ac Power Output (VA)	3,800 @ 240V	6,000 @ 240V	7,600 @ 240 V	10,000 @ 240 V	11,400 @ 240 V
AC Output Voltage Range (Vac)	240	240	240	240	240
Max Total PV Input Power (240V DC)	7.6 kW	12 kW	15.2 kW	22.0 kW	22.8 kW
Max. PV Input Current per String @ 240V (dc)	10.5 A / 2520 W	16.5 A / 3960 W	20A / 3720 W	30.5 A / 7320 W	30.5 A / 7320 W
Smart EV Charger AC Max (Grid/Battery/PV) (W)	9600W (Level 2)	9600W (Level 2)	9600W (Level 2)	9600W (Level 2)	9600W (Level 2)
Min Electrical Service Size (Amps), OR:	100A	200A	200A		
Minimum Busbar Rating (Amps)	100A	**125A**	**125A**		

Solar Edge – Three Phase Inverters

	SE3800H-US	SE5000A-US	SE6000H-US	SE11400H-US	SE10000A-US
					
Maximum Ac Power Output (VA)	3,800 @ 240V	5,450 @ 240 V	6,000 @ 240V	11,400 @ 240 V	10,950 @ 240 V
AC Output Voltage Range (Vac)	240	240	240	240	240
AC Frequency (Hz)	59.3-60-60.5	59.3-60-60.5	59.3-60-60.5	59.3-60-60.5	59.3-60-60.5
Max. Input Current @ 240V (dc)	10.5 A / 2520 W	15.5 / 3720 W	16.5 A / 3960 W	30.5 A / 7320 W	30.5 A / 7320 W
Min Electrical Panel Size (Amps)		100A			

Low-Cost Resilience

A full home sized solar array and battery system can be costly, so this section aims to provide products that can help improve your home's resilience, but for an affordable cost. When the power grid goes down, having a back up power for lighting and phone charging at a minimum is essential. This section also provides a solution to propane fueled camp stoves.

Electric Generators

Electric generators are high-capacity batteries that can provide power to range of devices (devices with 12V car ports that use DC power or devices with 120V plugs typical in a home). To recharge the internal battery, you can use solar, car batteries, or directly from the grid. The batteries go up in cost as their capacity increases which is measured in Watt-hours. For example, the Goal Zero Yeti 500X could power a 10-Watt lightbulb for 50 hours or could charge a 12W smart phone 42 times. The largest two batteries shown below, have a higher rate of power supply (amperage) which enables them to power more energy/power consuming devices. As another example, the Goal Zero Yeti 6000X could run an average full-sized fridge (100W) for 60 hours.

Picture	**Pecron** S200 	**Rockpals** 	**RIVER** 600 	**Goal Zero** Yeti 500X 	**Goal Zero** Yeti 1500X 	**Goal Zero** Yeti 6000X 
Price	$170	$220	$350	$700	$2000	$5000
Solar charging	Yes	Yes	Yes	Yes	Yes	Yes
Battery Capacity (Wh)	193	288	288	500	1500	6000
Output Voltage (V)	5, 12 (VDC) 120 (VAC)	5, 12 (VDC) 120 (VAC)	5, 12 (VDC) 120 (VAC)	5, 9, 12, 20 (VDC) 120 (VAC) / 2.5A	5, 12, 20 (VDC) 120 (VAC) / 16.5A	5, 12, 20 (VDC) 120 (VAC) / 16.5A
Full charge time with 120VAC input (hrs)	6-7	6-7	1.6	4.5 (120V/1A)	7 (120V/2A)	12 (120V/5A)

Electric Cooking on Small Batteries

Electric cooking devices such as induction stovetops are viable alternatives to natural gas cooking options because they eliminate the risks of burning natural gas. However, typical induction stoves require a lot of power and can use up battery storage quickly. The alternative cooking devices shown below can be powered by electric generators more efficiently and use a typical car outlet (which are in all electric vehicles as well). For example, the RoadPro car frying pan can run for 8.3 hours using the Goal Zero Yeti 1500X. Keep in mind only the larger electric generators will pair with these cooking devices because of their amperage draw.

	RoadPro Car Frying Pan 	**RoadPro** Car Oven 	**RoadPro** Crock Pot 
Price	$30	$35	$50
Watts	180	144	150
Voltage	12V DC	12V DC	12V DC
Amps	15	12	12
Run time with Goal Zero Yeti 1500X (hr)	8.3	10.4	10

Back-up Battery Light Bulbs

These Light bulbs are equipped with backup batteries that stay charged while power is being supplied as normal and get discharged when power goes out. This is a viable option for areas that require constant lighting and cannot be disturbed even during power outages.

Picture of the LED Light Bulb + Battery				
Model	GE - A21	YKDtronics	JackonLux	Neporal
Lighting Hours on Battery Power (hrs)	5	3-4	3-4	4-5
Wattage (W)	8	5	9	15
Lumens	760	500	850	800
Lumens/Watt	95	100	94.44	53.33
Price	$15	$8	$9	$11

Electric Camp Stoves and Grills

Biolite CampStove 2 is a camp stove that burns twigs found at any campsite with a battery-powered fan that creates a vortex of hot, smokeless fire. Biolite cooks food quickly while simultaneously recharging the battery from the heat, which is transformed into electricity and can additionally charge a headlamp or cellphone. This Biolite is perfect for backpacking because it is lighter than the average butane canister. An additional grill attachment also available, shown in the image on the right above, for cooking small meals. This model also provides the option of USB charging for small electronics. The specs for the stove are below:

- Charge phones, lights, and more with 3W generated power
- Burn twigs, sticks, wood scraps, or pellets
- Boil Time: 1L in 4.5 min
- Battery Capacity: 2600 mAh
- Packs down to size of a 32oz wide mouth water bottle
- Weight: 2.06 lbs

BioLite FirePit: Enjoy the warmth, smell, crackle, and feel of a wood campfire, but fan-assisted to reduce smoke. With capacity for up to 4 standard firewood logs, the BioLite FirePit creates hyper-efficient flames with patented airflow technology and gives you a front-row seat to the magic thanks to the X-Ray mesh body, enabling 360 views. Lift the fuel rack and toss in charcoal to transform it from a fire pit to a portable hibachi style grill, complete with an included grill grate. Control the size of your flames manually or remotely with the free Bluetooth app.

- Fuel: Burns firewood or charcoal
- Burn time: 24hr on low, 10hr on medium, 5hr on High
- Dimensions: 27" x 13" x 15.8"
- Weight: 19.8 lbs

Electric Battery Storage

Battery storage provides resiliency during disasters and shorter power outages, 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 turbines, 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. The Clean Coalition has developed the "Electrification and Community Microgrid Ready" (ECMR) document to guide the easy and inexpensive installation of prewiring for grid interactive solar plus energy storage systems.[145]

Battery Systems

Battery system prices 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.[146] Home batteries can be modest and scaled to a reduced set of power needs during outages, 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.[147] 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)	

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. In addition, solar thermal can an efficient way to heat pools or supplement pool heating.

Contractor perspectives on heat pump pools:

- **They are simpler**: Heat pump pool heaters are relatively new to most contractors on the market in the Bay Area, but a common consensus is that heat pump pool heaters are simpler to install than gas pool heaters in new single-family construction because of the challenges of running gas lines compared to the simplicity of a 40-Amp electrical wire in residential settings.
- **They work well**: Heat pump pool heaters work well year-round, and Hayward and AquaCal are the locally favored brands due to their contractor technical support. AquaCal is especially favored for integration into automatic of pool covers. The AquaCal HeatWave SuperQuiet lives up to its name and is especially quiet.
- **They cost less to operate**: Heat pump pool heaters save pool owners on their utility bills compared to gas because they collect 5 or more units of heat for every 1 unit of electricity, while gas pool heaters use 6 times as much energy, collecting only 0.8 to 0.9 units of heat for every 1 unit that is burned. [148] See cost calculations in the Appendix for further detail.
- **Winter pools should be paired with efficiency measures**: Pool covers dramatically reduce heat loss, and contractors also advocate for automatic pool covers. Floor return lines, which prevent stratification (cold water at the bottom of the pool and hot water at the top) are common in older pool designs and are an important efficiency measure. See the schematic in the Appendices. Large outdoor pools that are kept warm during the winter can use multiple standard heat pumps that are designed to be integrated together to meet the higher heating demand. Generally these are plumbed in parallel, with a logic system for automation such as Hayward Omnilogic[149], and no storage tank.
- **More skilled contractors are needed in the pool industry**: EPA 608 Technician[150] Certification is recommended for pool contractors to service the refrigeration components of heat pump pool heaters, and indicates a level of training similar to HVAC professionals. There are workarounds, including partnering with an HVAC professional who has the certification, but that can add additional delays to the repair due to scheduling. EPA 608 is not necessary to install most new construction heat

Figure 40: Pacific Companies Zero Net Energy apartment complexes built in 2014 with heat pumps for the hot tub and swimming pools. (left King Station Apartments, King City, CA and right Belle Vista Senior Apartments, Lakeport, CA.)

Sizing a heat pump pool heater

To right-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. Most heat pumps are sized for back yard pools (10’ x 20’ x 5.5’ = 8,228 gallons, 15’ x 30’ x 5.5’ = 18,513 gallons, 20’ x 40’ x 5.5’ = 32,912 gallons).

Right-sized heat pump pool heaters are designed to run without interruption and can modulate their heat output to match both large and small demands. By contrast, gas-fueled pool heaters will cycle on and off rather than overheat, particularly during summer weather when only a small amount of heat is needed to maintain the pool temperature relative to winter use. In addition, a heat pump can also cool the water in your pool where a gas heater cannot. A well-sized pool heat pump can raise and maintain the temperature of the water +30 degrees above the source water temperature. The source water temperature depends on where you live – the ground temperature is roughly equal to the last months average air temperature. For example, if the previous month's average air temperature was 50 degrees you can assume this month's ground temperature is 50 degrees and you can heat the water in your pool up to around 80 degrees. Aquacal provides an excellent heat pump pool heater sizing estimator that also performs cost-of-use estimates: https://www.aquacal.com/sizing-and-savings-calculator/

The benefit of using pool covers:

- Reduces the need for pool cleaning and can help reduce energy bills
- Using a pool cover properly can halve your pool heat pump sizing by preventing heat from escaping.
- Pick a dark-colored, solid material for improved solar heat absorption.[151]
- Automatic pool covers are a convenient and aesthetic option.
- A traditional, manual pool cover made of vinyl will achieve the same efficiency benefit as an automatic pool cover if used properly.

One of the author's brother enjoying a heat pump pool in New York.

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 5 to 8 months of renewable pool heating with solar thermal panels. The key technology involved in heat pump operation at low temperatures is pairing an **inverter** with the compressor, which allows the compressor to operate at multiple speeds depending on the output needed due to environmental conditions. Inverter-compressor units are often called "Variable Speed" or "VS". Below is a sample of heat pump pool heaters.

	Hayward HeatPro VS Variable Speed	**Pentair** UltraTemp 110 Heat Pump	**AquaCal** HeatWave SuperQuiet SQ166R ICEBREAKER	**AquaCal** Heatwave SuperQuiet Variable Speed SQ150VS	**AquaCal** Great Big Bopper	**Arctic** 060ZA/B
						
Price	$3,000	$3,270	$4,800	$5,700	$40,000	$4,400
Heating Capacity (BTUh)	90,000	108,000	126,000	115,000	527,000	88,030
Inverter Driven?	***YES***	***NO***	***YES***	***YES***	unknown	***YES***
Heating COP	5.1	5.8	5.6	5.0	6.6	6.2
Temp. Range	**30°F Air***	**45°F Water***	**25°F Air***	**25°F Air***	40°F	**-4°F**

**The lowest operating weather condition specification is based on conversations with manufacturers but has not been verified by AHRI or other third-party testing programs, and operating any pool heater (including gas) below freezing will produce inconsistent results.*

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 have made improvements to traditional steam saunas. This style of products uses low intensity infrared lights to increase body and air temperature, which is better for the lifetime of the wood rooms and creates an enjoyable experience comparable to steam.

240V: Electric Resistance, heater unit only

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

120V: Infrared, Full Room

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

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.

Residential

	Blower	**Chain Saw**	**Pole Pruner**	**Trimmer**	**Hedge Trimmer**	
STIHL[152]	BGA 45 ($130) 	MSA 120C ($350) 	HTA 65 ($660) 	FSA 56 ($150) 	HAS 56 ($280) 	RMA 460 ($420) 
Husqvarna[153]	320iB ($230) 	120i ($260) 	536LiP4 ($400) 	336LiLC ($250) 	115iHD55 ($230) 	LE121P ($450) 
RYOBI[154]	RY40411 ($170) 	RY40530 ($200) 	P4361 ($140) 	P2080 ($130) 	P2660 ($130) 	RY48110 ($2700) 

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

Commercial

	Blower	Chain Saw	Pole Pruner	Trimmer	Hedge Trimmer	
STIHL[155]	BGA 100 ($350) 	MSA 160 C-BQ ($350) 	HTA 85 ($490) 	FSA 130 R ($400) 	HAS 94 R ($500) 	RMA 510 ($520) 
Husqvarna[156]	550iBTX ($500) 	T536Li XP ($400) 	536LiPT5 ($500) 	536LiLX **($300)** 	536LiHD60X ($430) 	LE221R ($430) 
RYOBI[157]	RY40440 ($270) 	P549 ($200) 	RY40561 ($200) 	RY40250 ($160) 	RY40610A ($150) 	RY48ZTR100 ($4100) 

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

Electric Fireplaces

Figure 41: A Dimplex Opti-Myst cassette within a commercial space.[158]

Figure 42: AFireWater fireplace in a home.

Swirling, fire-like mist lit with LEDs and a campfire's worth of heat: these are electric fireplaces. They are less expensive to purchase and install than gas stoves, safer, cleaner, and plug into a normal 120V wall outlet. They provide heat in a more efficient and smokeless way – an electric fireplace can warm a room 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?

An ultrasound vibrator breaks water into ultra-fine water vapor, with small fans and LED lights producing extremely realistic mist "flames." The LED lighting allows for both natural and artistic colors of flames. The height of the flames can be customized as well by adjusting the opening where the water vapor comes out. Opti-Myst and AFireWater have many different styles of LED water vapor fireplaces to provide ambiance in residential, commercial, and high-rise buildings.

Why buy a water vapor and LED fireplace?

These mist-and-LED are the safest and cleanest electric technologies to put within a home or office. Unlike real fireplaces, they are not emitting soot, smoke, carbon monoxide or other combustion byproducts into a space, and can be controlled via a smart phone for optimal aesthetics. Fireplaces can now be safely enjoyed by pregnant mothers and small children without worry about health impacts from air pollution.

Manufacturer and Product Image	**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

Manufacturer and Product Image	**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

Manufacturer and Product Image	**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 maintenance and can also be used in high rise buildings where typical combustion grills are not allowed due to fire code restrictions.

Manufacturer and Product Image	**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

Manufacturer and Product Image	**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

Manufacturer and Product Image	**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

Electric Snowblowers

There is a wide range of electric snowblowers on the market ranging from a few hundred up to about 800 USD. Their lack of a need for maintenance makes them extremely convenient. This equipment does not require oil changes, filter changes, new spark plugs, or any gasoline. This also makes storage and usage safer for the operator. Electric snowblowers, on average, are significantly quieter than their gasoline counterparts making blowing before work in the morning much more bearable for you and your neighbors. This clean, quiet, and efficient alternative to gas now also is readily available as battery powered rather than corded, giving you all the freedom of a gas-powered engine without the hassle.

Manufacturer and Product Image	**EGO** SNT2102 	**Snow Joe** iON18SB 	**PowerSmart** DB2401 	**Earthwise** SN74018 	**Toro** 38381 	**Snow Joe** Ultra SJ620 
Lbs. of snow/ minute	1500	500	700	500	700	650
Terrain conditions	Paved & Gravel	Flat/Paved	Flat/Paved	Flat/Paved	Flat/paved	Flat/paved
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
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		
Motor Type					15 Amp Series Wound Electric	13.5 Amp
Throwing distance	35ft	20ft	30ft	30ft	30ft	20ft
Clearance	21" wide & 10" deep	18" wide & 8" deep	18'' wide & 11'' deep	18'' wide & 12'' deep	18" wide & 8" deep	18" wide & 10" deep
Weight	70 lbs.	32 lbs.	18.5 lbs.	35 lbs.	25 lbs.	31.5 lbs.
Price	$604*	$300*	$270*	$250*	$280	$150

*batteries and charger included

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