CENTRAL HEAT PUMP WATER HEATER DESIGN GUIDE

SOLUTIONS AND TOOLS FOR DESIGNING CENTRAL HEAT PUMP WATER HEATER SYSTEMS IN MULTIFAMILY AND OTHER COMMERCIAL BUILDINGS

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Cover photo:
Heritage Square Apartments, Pasadena. Photo by Evan Green, Ecotope.

Energy Trust of Oregon

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INTRODUCTION

This design guide is intended to help consulting design engineers become familiar with how to design central heat pump water heater (CHPWH) systems in commercial buildings, in particular multifamily and other multi-tenant residential uses. It gives an overview of different system configurations commonly used in multifamily residential building installations today, including pros and cons of each system configuration and the effect on overall energy usage. It also identifies publicly available design tools, covers products currently on the market, and includes case study references.

Topics included in this guide:

- System designs
- Sizing
- Equipment layouts
- Importance of considering system coefficient of performance (COP)
- Short list of manufacturers, products and case study references, other resources

Current energy codes and standards are pushing for the adoption of more energy-efficient, load-flexible electric solutions to building energy usage. Heat pump water heaters (HPWH) are a key technology identified to meet carbon reduction and climate goals. They have the potential to reduce the energy used for water heating by a factor of approximately three, if properly designed. In addition to overall energy savings, HPWH systems naturally allow for load shift capability. A typical HPWH system is designed with less heat capacity and more storage than a traditional electric or gas water heating system. The high storage volume makes CHPWH systems available for load shift and demand response scenarios.

SYSTEM DESIGNS

Good CHPWH system design is critical to functioning and achieving high COP. If the HPWH system is configured and sized like a traditional gas boiler system, the building owner will be left with functional issues and poor performance. This section outlines common strategies for configuring central HPWH systems.

In order to integrate HPWH systems, designers need to be able to choose a system configuration appropriate for the application. System configuration is driven by a number of variables, including the type of heat pump technology deployed, how water is circulated through the building, and how water temperature is maintained during low hot water demand conditions. The impact of these variables on system configuration is discussed below.

HEAT PUMP WATER HEATER TECHNOLOGIES

Before choosing a CHPWH system, it is important to understand the two major categories of HPWH equipment sold in the US today: single-pass systems and multi-pass systems. The two basic configurations are shown in Figures 1 and 2. This terminology refers to whether the water is fully heated from incoming supply temperature in a single-pass through the HPWH, or whether the water is heated by cycling through the HPWH equipment multiple times with a small temperature lift in each cycle. The two configurations require different storage and control parameters, interface differently with supply and circulating loops, and may deploy different refrigerants. A subcategory of multi-pass systems includes unitary heat pump water heaters, where the compressor and storage tank are combined into a single appliance. This configuration is most common in residential-scale equipment, though some larger unitary systems are available on the market for commercial applications. Larger unitary systems are particularly appropriate for food service and grocery applications.

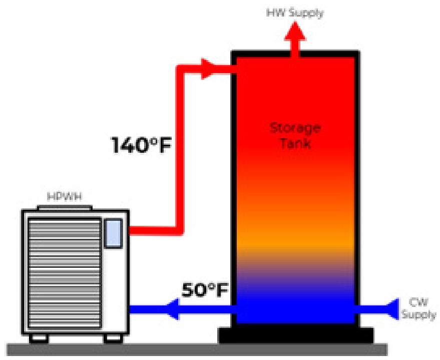

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Figure 1: Single-pass: Heats water to the storage setpoint temperature in a single water pass through the refrigeration circuit, typically a 70°F to 100°F temperature lift in a single cycle

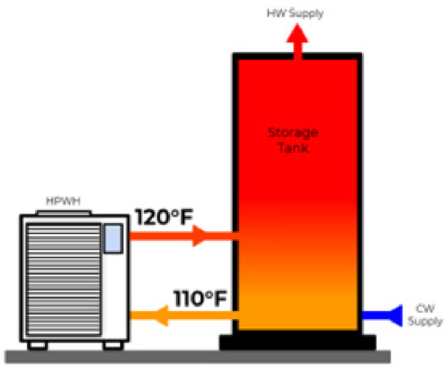

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Figure 2: Multi-pass: Heats water to the storage setpoint temperature in a multiple water pass through the refrigeration circuit, typically a 10°F temperature lift for each cycle

Most refrigerants currently used in HPWHs can be used in single-pass or multi-pass configurations. However, CO_2 works best in single-pass HPWHs. Most systems used today are single-pass HPWHs, which have a number of advantages over multi-pass systems:

- Less storage is needed in single-pass HPWH systems because the recovery time is shorter with the same capacity.
- Higher temperatures used in single-pass systems allow for better legionella control.
- CO_2 as a refrigerant has the lowest global warming potential (GWP) of any refrigerant currently available.

Publicly available design tools for sizing currently only work for single-pass systems. See System Sizing: Ecosizer section below.

SYSTEM CONFIGURATIONS

The domestic hot water (DHW) heating system is tasked with satisfying two main heating loads: primary and temperature maintenance. Primary heating is the process of heating cold city water up to DHW temperature to be delivered to occupants through their hot water plumbing fixtures. As the DHW water circulates through the building, the hot water piping loses heat to its surroundings and the DHW cools. The temperature maintenance load is the heat required to prevent the circulated water from over-cooling in the pipes, especially during off-peak periods when there is little DHW demand. If DHW is sent to the building at 125°F, it is circulated through the building and the water that is not delivered to the fixtures may return to the heating plant at a temperature closer to 115°F before it is reheated. The way this return water is treated sets up two types of system configurations: 1) a return to primary system where the return water feeds directly into a multi-pass heat pump system, or 2) a temperature maintenance system where a single-pass heat pump generates hot water from incoming supply while a separate temperature maintenance system maintains the water temperature in the circulating loop.

DEDICATED TEMPERATURE MAINTENANCE SYSTEMS

Since primary single-pass HPWHs—tasked with heating the primary load—work more efficiently when heating incoming cold water, the warm circulation return water (temperature maintenance load) is often reheated by a separate, dedicated heating system.

The equipment employed to heat the temperature maintenance load often includes a dedicated temperature maintenance tank and additional temperature maintenance heater. The dedicated temperature maintenance tank receives the warm circulation return water that would otherwise destratify the primary storage tank, which would cause a decrease in primary HPWH efficiency. There are two proven methods for configuring a dedicated temperature maintenance system: 1) Swing Tank, shown in Figure 3; and 2) Parallel Loop Tank, shown in Figure 4. These and other configurations are described below.

SWING TANK

The swing tank design uses an unstratified tank (called the "swing tank," or "series temperature maintenance tank" as seen in Figure 3) that is plumbed in series with the primary storage tank(s). As water is used by the occupants, hot make-up water flows from the high temperature primary storage tank and through the swing tank on its way to the fixtures. The primary storage water—much warmer than required delivery temperature—mixes with and heats the water in the swing tank as it passes through. Swing tank temperature will be highest during periods of heavy DHW use because there is a large flow of overheated water passing from the primary storage tank and through the swing tank on its way to the fixtures. During periods of low usage, the temperature in the swing tank will slowly drop. If the swing tank temperature drops too far, an electric resistance heating element will turn on to ensure the returning water circulation loop

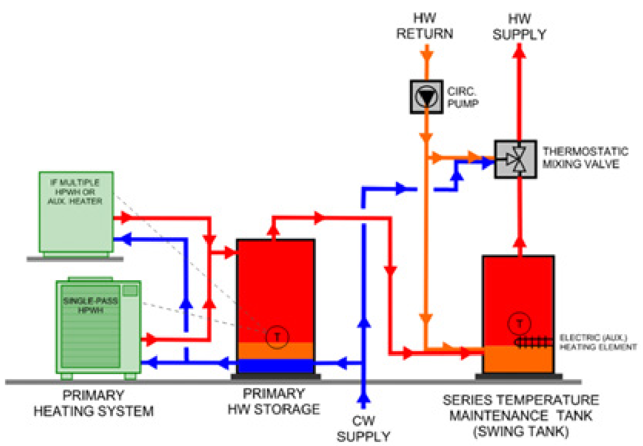


Figure 3: Single-pass primary HPWH system with series temperature maintenance tank (Swing Tank)

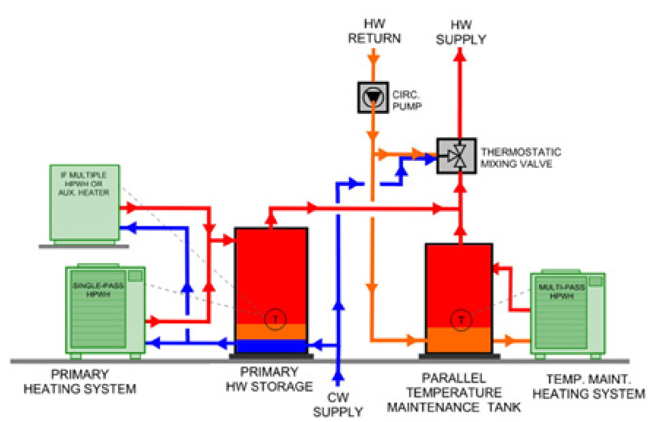


Figure 4: Single-pass primary HPWH system with parallel temperature maintenance tank and multi-pass HPWH (Parallel Loop Tank)

load does not overcool the swing tank, which would result in cool water delivered to the building. The passive heating of the swing tank system—heat transferred from the primary storage into the swing tank—allows the highly efficient primary HPWH to provide a significant portion of the temperature maintenance heating.

PARALLEL LOOP TANK

When using a parallel loop tank design (Figure 4), the recirculation losses are reheated using a separate multi-pass heat pump. This configuration uses dedicated heat pumps for both the primary and recirculation heating. In a parallel loop tank configuration, the primary storage temperature can be kept lower if desired. A lower primary storage water temperature can allow heat pumps to operate more efficiently but may require a larger storage volume. More heat pumps are required in this configuration, which adds cost. Additionally, since overall HPWH capacity is reduced in cold weather, a parallel loop tank configuration may require additional heat pump capacity if the compressors are subject to cold ambient temperatures. The parallel temperature maintenance system is a good solution in applications with high temperature maintenance losses and relatively low DHW usage because the parallel temperature maintenance system utilizes a high-efficiency HPWH to satisfy the temperature maintenance load and does not require flow from the primary storage to provide passive temperature maintenance heating.

RETURN TO PRIMARY SYSTEMS

While it has many advantages, using separate temperature maintenance heating equipment requires additional equipment, which adds cost and takes up more floor area. When equipment can heat warmer incoming water efficiently, and recirculation losses are low, maintaining stratification is less important and return to primary systems are appropriate.

MULTI-PASS RETURN TO PRIMARY

One of the major appeals of multi-pass return-to-primary HPWH systems is the familiarity designers and building operators have with their piping configuration. Multi-pass HPWH systems are plumbed almost exactly as conventional gas water heating systems, as can be seen in Figure 5. However, there are some significant disadvantages:

- Multi-pass return-to-primary systems require higher HPWH capacity than single-pass systems serving an equivalent load, leading to higher costs for equipment.
- Recovery time is longer with multi-pass systems since the water must pass through the heat pump multiple times to reach delivery temperature.

Multi-pass HPWHs tend to be less efficient than single-pass HPWHs because of increased pumping energy and longer operating times.

SINGLE-PASS RETURN TO PRIMARY

Single-pass, return-to-primary HPWH systems, shown in Figure 6, offer another approach to installing systems without dedicated temperature maintenance equipment, but they require single-pass primary heaters that are specifically designed for this configuration. Single-pass HPWHs employed in single-pass return-to-primary configuration must be capable of heating entering hot water to high temperatures efficiently because temperature maintenance flow is routed to the bottom of the primary storage tank near the location that is feeding the primary HPWHs. That means the storage tank is stratified, but in times of low DHW usage, the water entering the heat pump is close to circulation return temperature (approximately 115°F). Controls should also be carefully considered because circulation return temperatures can interfere with single-pass HPWH control sequences. Warm circulation return water may conflict with the "on" setpoint of 100-115°F that is typically used with single-pass HPWHs. Manufacturers that offer R134a or R410a HPWHs with single-pass control, like Colmac and Nyle, are proponents of single-pass return-to-primary configuration and recommend appropriate control sequences that complement this configuration.

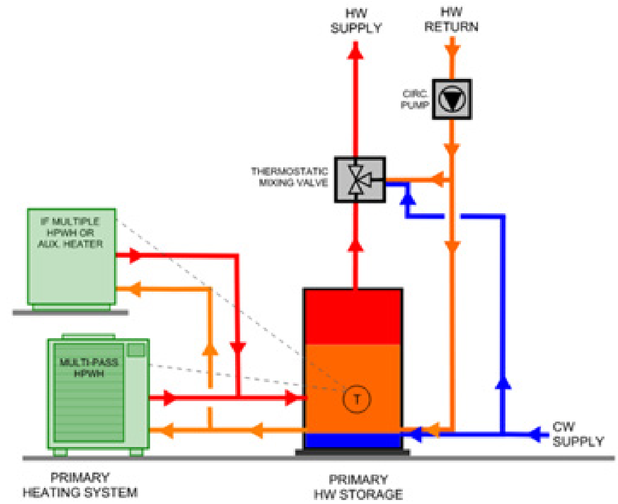


Figure 5: Multi-pass primary HPWH system with hot water return to primary storage

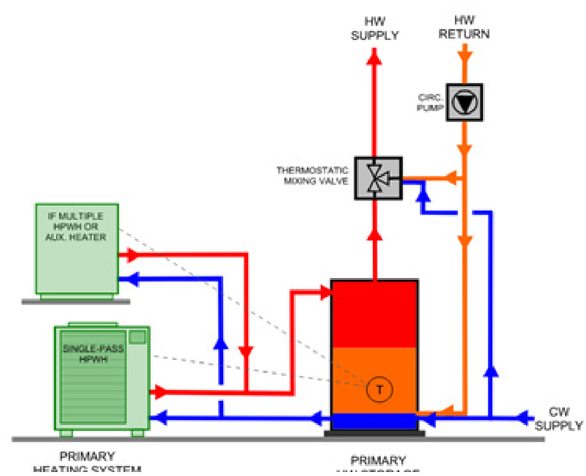


Figure 6: Single-pass primary HPWH system with hot water circulation returned to primary storage tank

NO RECIRCULATION

If DHW fixtures are located close enough to the DHW plant, installation of a DHW circulation loop may not be necessary. This situation is very beneficial for HPWH system design because it is no longer necessary to worry about the impact of warm return water circulation on HPWH performance. This configuration also substantially reduces pumping energy associated with a recirculation system. The HPWHs that thrive from this configuration are single-pass HPWHs and integrated HPWHs. They can be configured as illustrated in Figures 7 and 8 on this page.

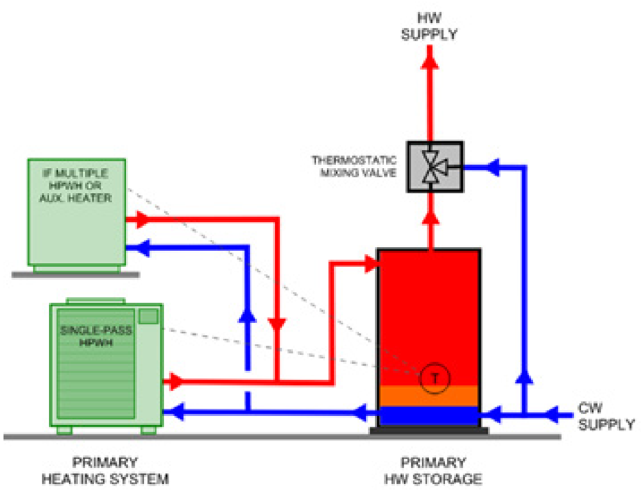


Figure 7: Single-pass primary HPWH system without hot water recirculation

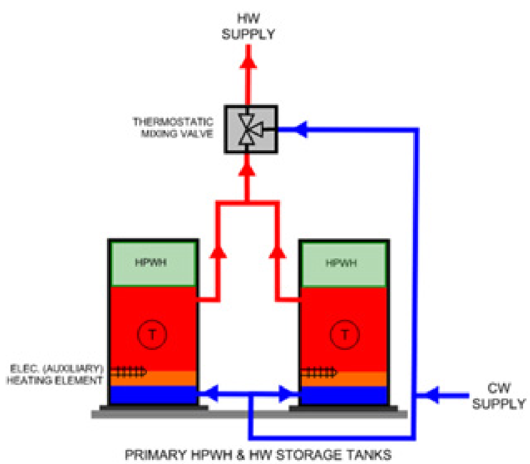


Figure 8: Multi-pass integrated HPWH system without hot water recirculation

INTEGRATED HEAT PUMP WATER HEATERS

Integrated HPWHs (also referred to as unitary HPWHs) are a type of multi-pass heat pump where the HPWH is directly integrated with the storage tank into a single appliance. This type of equipment has been implemented very successfully in single-family residential homes. However, designers should be careful when implementing them in commercial applications. The on-board controls of integrated HPWHs have been designed for residential loads with minimal or non-existent temperature maintenance loads. When integrated HPWHs have been installed in multifamily applications with relatively significant temperature maintenance loads, researchers have found the electric-resistance elements fire frequently. This results in relatively low efficiency relative to commercial HPWH systems that have been installed in the configurations explained above. Unless this situation can be specifically resolved, it is recommended that integrated HPWHs only be installed in systems without DHW circulation systems. Food service and grocery uses represent good applications of integrated systems.

STRATIFICATION

In single-pass heat pumps, thermal stratification in the primary storage is critical for efficient HWPH operation. Many single-pass HPWHs require a large heating temperature lift for stable and efficient operation. Therefore, the bottom of the storage tank should be kept cool while hot water generated by the HPWHs is directed to the top of the storage tank(s). In systems where warm return water from the circulation system is piped back into the storage tank(s), the water in the tank is continuously circulated, reducing tank stratification. This configuration is more appropriate for multi-pass heat pump configurations.

REFRIGERANTS

Refrigerant types have different thermal and pressure characteristics that impact which types of systems are most effective for them, the peak water temperatures they can deliver, and the ambient temperatures in which they can operate effectively. Refrigerant characteristics therefore set parameters for system design based on ambient temperatures and operating characteristics. Different manufacturers tend to focus on different refrigerant types, so individual manufacturers may not have HPWH equipment capable of meeting all possible design parameters. Refrigerants also have different environmental characteristics. Some refrigerants are scheduled for phase-out based on adverse climate impacts, adding complexity to refrigerant selection issues.

COMMON REFRIGERANTS IN HEAT PUMP WATER HEATER SYSTEMS

The three most common refrigerants in HPWH systems currently available in the United States are R-134a, R-410a and R-744 (CO_2). Engineers should always consult the manufacturer to understand operating conditions of the specific HPWH make and model. While operating parameters are highly dependent on the specifics of refrigerant cycle design, the characteristics of refrigerants themselves also play a role. Consider the descriptions below as general, based on experience designing with HPWH equipment manufactures from 2000 to 2020.

R-134a

This refrigerant can be used to bring water temperatures up to about 160°F but cannot be used in low ambient air temperatures. The output capacity begins to drop off steeply below about 60°F ambient air temperatures, and output capacity and efficiency are extremely low below about 40°F. Equipment using this refrigerant is suitable for outdoor applications in warm humid or mild climates, but is not recommended in climates with a significant number of hours below 40°F. In mild climates like the Pacific Northwest, this equipment can sometimes be installed in below-grade parking garages or other spaces that are significantly buffered from winter low temperatures.

R-410a

This refrigerant can be used in climates subject to very low ambient air temperatures (as low as 0°F). However, most equipment using this refrigerant is not able to deliver potable water temperatures above about 125°F. Even this temperature is difficult to deliver with R-410a when ambient air temperatures fall below about 40°F. Because of this upper limit in delivery temperature, HPWHs using R-410a will often deploy a booster tank (also referred to as a trim tank or finishing tank) to bring the water temperature up to the final delivery temperature.

R-744 (CO_2)

This refrigerant can bring water temperatures up to 180°F or above, and can operate in cold ambient temperatures below 0°F. However, the refrigerant must be maintained at a very high pressure relative to alternatives, which limits the absolute piping distance between the compressor and condenser; this creates a need for strong and effective pipe connections. CO_2 has the lowest global warming potential of any refrigerant currently used in HPWH technology in the U.S. market.

REFRIGERANT TRANSITION

In addition to impacting configuration and performance, the global warming potential of different refrigerants impacts the market characteristics of different HPWH equipment as well. Both 410a and 134a were developed to replace ozone-depleting refrigerants but they have relatively high global warming potential. The Kigali Amendment to the Montreal Protocol identifies international phaseout requirements for these two refrigerants. By 2035, the refrigerants R-134a or R-410a will no longer be allowed for new equipment in the market. Furthermore, some jurisdictions, including the State of California, have adopted accelerated phaseout schedules for these refrigerants.

This complicates the transition to HPWH technology, as manufacturers and specifiers evaluate how much to invest in equipment that uses refrigerants targeted for elimination. While some potential replacement refrigerants are becoming available (R-32 and R-1234YF), it is not clear if these refrigerants will represent direct substitutes in existing equipment configurations for 134a and 410a. The replacements may change the performance patterns and capabilities of some equipment, or they may fail to meet performance specifications for some equipment. This introduces significant uncertainty into the market over the mid-term. From a climate standpoint, CO_2 refrigerant is a clear winner, and more equipment using this refrigerant will probably be encouraged and deployed over the next several years.

EQUIPMENT LAYOUT

CONSIDERATIONS FOR LOCATING HEAT PUMP WATER HEATER COMPRESSORS

Although the HPWH is often located outdoors, HPWHs can also be located in parking garages. In cooler climates, HPWHs installed in parking garages can take advantage of buffered winter temperatures to operate more efficiently. Measurement and verification studies in Seattle, Washington found that installing units in parking garages kept the minimum inlet air temperature to above 50°F annually, when the outdoor air temperature often dropped much lower. When installing a HPWH in a parking garage, it is recommended to exhaust air from the HPWH directly outdoors or interlock the garage exhaust fan and the HPWH and direct HPWH exhaust to the garage exhaust fan.

Engineers should also consider the following when locating the outdoor HPWH unit.

- Mount the outdoor heat pump unit allowing for access to front service panel. Provide clearances for airflow per manufacturers instruction.
- Allowable vertical and horizontal distance between the outdoor HPWH and the storage tanks and recirculation system.
- Do not place the unit so that its air intake sides face into the prevailing wind. The preferred orientation for air intake is perpendicular to prevailing winds.
- Do not place unit close to windows, especially those in sleeping areas or other locations where the sounds of the unit's compressor and fans would be objectionable.
- Do not place unit where the air intake sides will be subject to accumulation of grass clippings, leaves, or other debris.
- Do not place unit directly under edge of roof where rainwater runoff will impinge on unit.
- Allow at least 12 inches between unit side and adjacent wall (follow manufacturer guidelines if different).
- Provide runoff so that condensate will not form puddles near unit.
- Do not install heat pumps such that discharge air from one heat pump is directed towards another heat pump.
- In cold climates, install so that units are elevated above snow accumulation.
- Preferred installation in cold climates is in a semi-protected alcove or other buffer space.

CONSIDERATIONS FOR LOCATING THERMAL STORAGE AND TEMPERATURE MAINTENANCE SYSTEM

Engineers should consider the following when locating thermal storage tanks and temperature maintenance system components.

Physical dimensions and height

CHPWH systems may be designed with larger volume storage tanks than conventional systems and may deploy multiple storage tanks in series or parallel. This equipment must be located on site with adequate room for installation and maintenance of other system components. Large storage tanks can be challenging to move around a construction site during installation. Additionally, the weight of large storage tanks can present issues both to new and existing construction. If located on an existing roof or structural slab, it is important to verify that the structural system can accommodate the load of the tanks when full of water. Seismic requirements, including strapping, should also be considered.

A floor sink and drain

This is required to serve as a drain for condensate and the pressure relief valve at the storage tank(s).

Thermostatic mixing valve

CHPWH system storage tanks may experience greater temperature fluctuations during normal operation than that of gas and electric resistance DHW systems. Storage tank temperature fluctuation may happen in both the primary storage tanks and the temperature maintenance tanks. This results in fluctuation of the water temperatures received by the HW side of the thermostatic mixing valve (TMV), which can then impact water delivery temperatures. This presents issues when mechanical type valves utilizing a paraffin wax or similar are used because they tend to respond slowly to temperature swings. A digitally controlled thermostatic mixing valve should be specified to ensure consistent hot water delivery temperatures to DHW fixtures.

Temperature maintenance system

The temperature maintenance system is often located near the thermal storage tanks. Similar to the thermal storage tanks, the engineers should consider spatial dimensions, weight, and seismic movement. A floor sink will be required for the pressure relief valve drain. The plumbing engineer must coordinate with electrical and structural engineers and provide 3' clearance in front of the swing tank where required by the National Electrical Code. Space and electrical connections must also be coordinated for the recirculation pump and mixing valve.

Secondary heat exchanger

For some configurations, a secondary heat exchanger is required by the plumbing code between the outdoor HPWH unit and the indoor storage tanks. When this additional equipment is required, additional space requirements near the tanks and floor drain will need to be coordinated.

CONSIDERATIONS FOR RETROFITS

Retrofitting an existing central gas or electric system with a central HPWH system can be challenging, and knowing what to look for during onsite visits early in the process can save time. When retrofitting, site visits must be performed to determine the existing conditions. Both the engineer of record and the contractor should perform site visits before starting design and construction.

Existing electrical capacity is one of the first things the engineer should consider—especially on gas water heating retrofits. If identified early in the process, upsizing an electrical panel can be done without issue. The design team would have to show that additional electrical capacity is available on the existing electrical service. In a case where the electrical service does need to be upsized to allow for enough electrical capacity, it can be a lengthy and costly process. Early identification can make the process much easier.

On initial site visits, the Engineer needs to determine a suitable location outdoors or in a parking garage for the HPWH and an indoor location for the storage tank, temperature maintenance system, and any ancillary components.

The HPWH needs to have a location to drain condensate—which can be drained into planter beds in some jurisdictions – and should meet criteria listed above under CONSIDERATIONS FOR LOCATING HEAT PUMP WATER HEATER COMPRESSORS. Do not overlook the importance of acoustics. HPWHs produce sound and locating them near tenant windows can cause complaints and owner dissatisfaction. Be sure to check the acoustic specifications of the unit and locate it an appropriate distance from any tenant windows.

The location of storage tanks and temperature maintenance system should meet criteria listed above under CONSIDERATIONS FOR LOCATING THERMAL STORAGE AND TEMPERATURE MAINTENANCE SYSTEM. If a floor drain is not available at the new equipment location, an existing clean-out can be used to dispose of condensate and pressure relief valve drainage.

Often the indoor equipment is installed in an existing mechanical room where existing equipment will be demolished. In certain situations, when tanks are not at end-of-life, existing tanks can be re-used as swing tanks. Re-using existing tanks as swing tanks is desirable in that it allows for an easier system switchover with less disruption to hot water usage. Existing electric resistance tanks make great swing tanks without much modification. When the existing fuel is gas, there are two options: if the gas tank has an integrated boiler inside the tank, it can be used as a gas swing tank. If the gas boiler is separate, the existing gas boiler can be kept and used as a swing tank, or the gas boiler can be replaced with a small, wall-mounted instantaneous gas or electric boiler.

A key consideration in retrofit projects is limiting disruption to DHW service to tenants. To limit service disruption, interim equipment installations or temporary service may need to be deployed to maintain residential occupancy. The logistics and mobilization required to limit service disruption can add significant complexity to retrofit projects.

SYSTEM SIZING

ECOSIZER

Ecotope inc. provides an online tool, the Ecosizer, for selecting heat pump water heating output capacity and associated storage volume for multifamily buildings. This tool is available at www.ecosizer.ecotope.com. A summary of the online selection process is illustrated in this section. For more information on the Ecosizer algorithm, please see the online documentation at www.ecosizer.ecotope.com/sizer/docs.

The Ecosizer calculates a total daily hot water demand using either the total number of people (ppl) and peak gallons per day per person (gal/day/ppl) or the number of apartments and California Residential Appliance Saturation Study (RASS) data. The number of people can also be calculated by occupancy rate and number of apartments.

Figure 9 shows options for calculating total hot water load on the Ecosizer website. Users must also input number of apartments in this section, which is used in distribution energy loss calculations.

Next, the user must input information about water temperatures and thermal storage. “Design Cold” indicates the city water temperature at design conditions; “Supply” is the temperature supplied to fixtures; and “Hot Storage” is the temperature setpoint for primary thermal storage. City water temperature will depend on geographic location, supply will be the designed hot water setpoint, and hot storage will be the thermal storage setpoint temperature or—for Mitsubishi’s QAHV systems—the supply output. Mitsubishi recommends a hot storage setpoint of 150°F in QAHV systems.

Advanced options in this section allow the user to modify thermal storage system parameters. The aquastat fraction is the position in the tank at which the heat pump will turn on. In most systems this should be roughly 1/3 of the way up from the bottom, so the aquastat fraction should be set to 30%. Some thermal storage tanks are specifically designed to increase stratification. If a specially designed storage tank is used, the design engineer should consult with the HPWH system manufacturer to understand the correct input for the storage tank they are using.

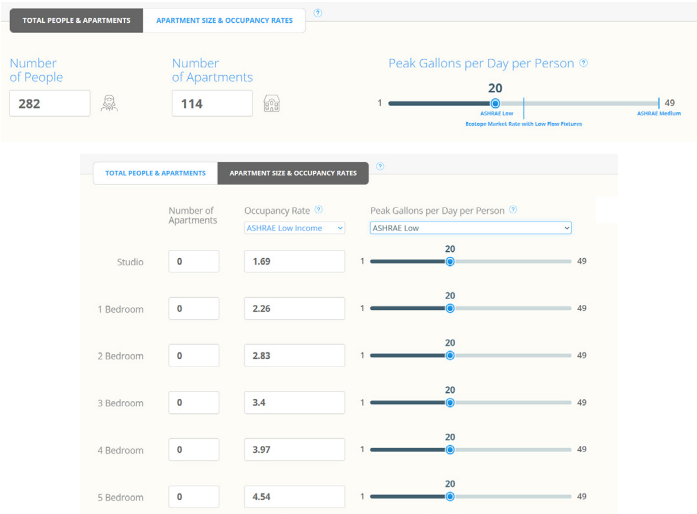


Figure 9: Ecosizer tool options for calculating daily hot water load

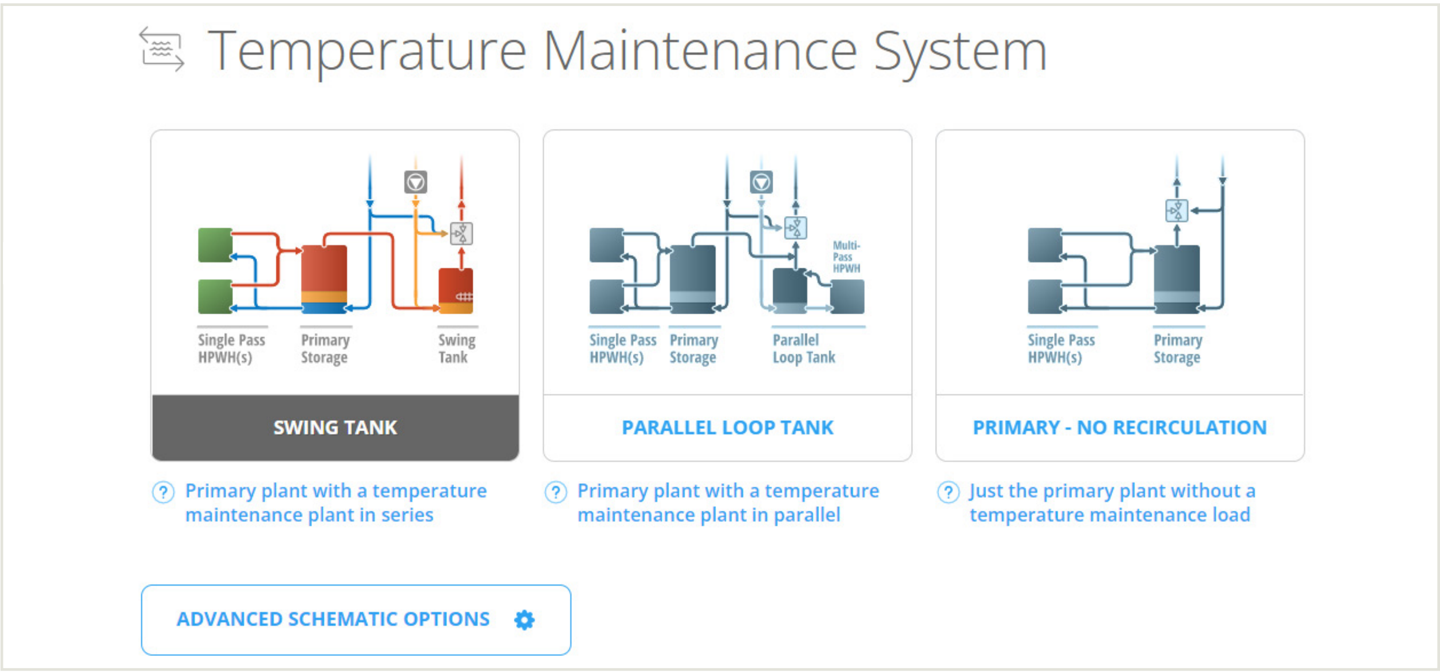
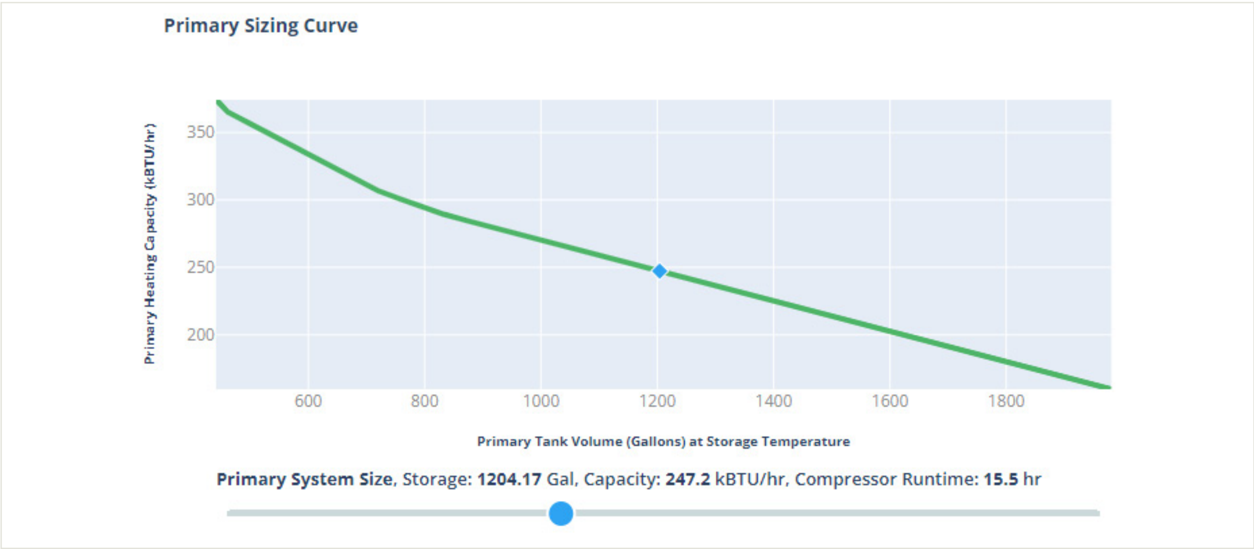
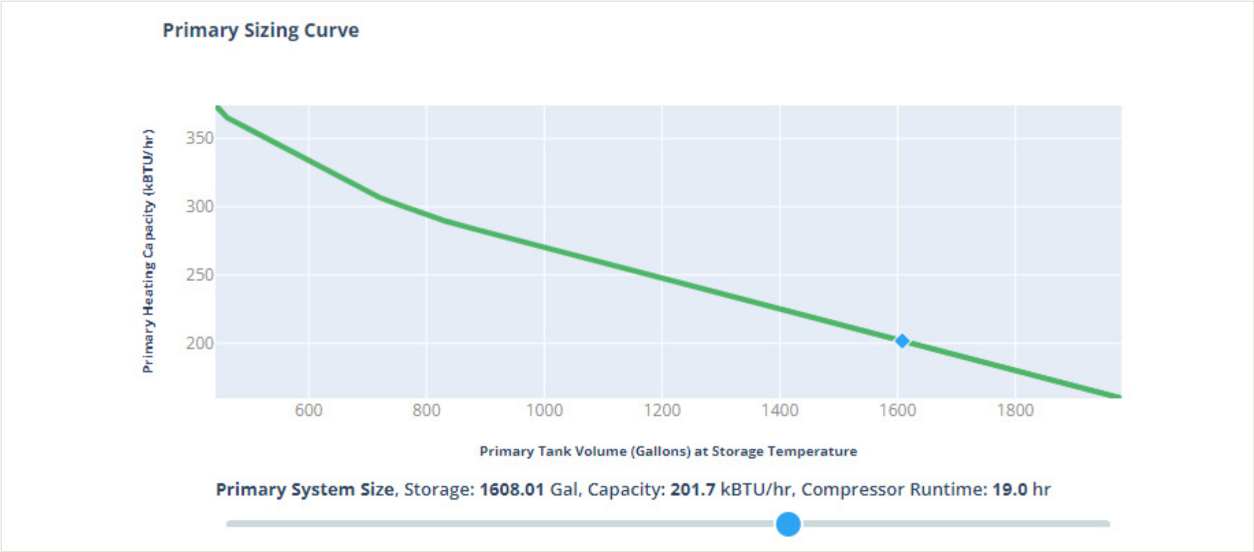


Figure 10: Temperature maintenance selection





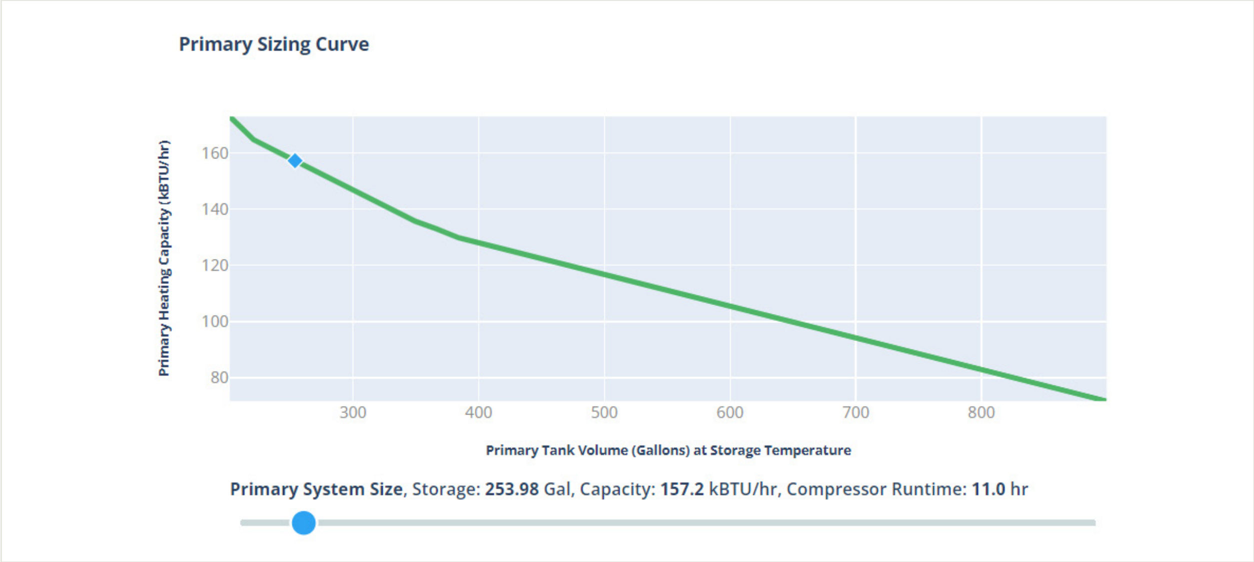


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Figure 11: Ecosizer capacity curve with selection example

Under temperature maintenance system, the engineer will select from one of three options:

1. Swing Tank
2. Parallel Loop Tank
3. No Recirculation

These systems correspond to the systems described under System Designs: System Configurations. There currently is no option in Ecosizer for return to primary.

In many cases, "swing tank" is selected for the temperature maintenance system as shown in Figure 10. A swing tank configuration allows the HPWH to offset a portion of the distribution losses. In some cases, when multi-pass HPWH is used to handle recirculation, parallel loop tank is selected. When the building has no recirculation loop, "primary - no recirculation" can be selected.

Advanced options under temperature maintenance allow the user two options for determining the energy loss through distribution piping. Based on a number of projects with measured data, it is recommended to leave the standard input of 100 W/apartment and a safety factor of 1.75 for new construction projects. For retrofit projects, it is possible to measure the recirculation flow rate and temperature change. Measuring the recirculation flow rate and temperature change, when possible, will lead to a more accurately sized temperature maintenance system.

After selecting "Size Your System," the Ecosizer will produce a primary sizing curve, equipment sizing recommendations, and a hot water simulation as shown in Figure 11. Ecosizer auto-selects the point on the curve that requires the HPWH to run for 16 hours on a peak day. However, the designer can use the slider below the plot to optimize a system for capacity or storage. Figure # shows three selections: one for a 16-hour runtime; one for more storage, less capacity and a longer runtime; and one for more capacity, less storage, and a shorter runtime.

The engineer is responsible for determining HPWH capacity at outdoor air temperature design conditions and the number of HPWHs needed based on the primary sizing curve. The engineer of record should review manufacturer documentation showing capacity at different outdoor air temperatures. The engineers also must remember to de-rate equipment for defrost if a defrost derate is not included in published capacity to outdoor air temperature plots. It is recommended that the engineer contact the manufacturer sales representative if they are unclear about capacity relative to outdoor air temperature or defrost derate.

Ecosizer recommendations provide swing tank capacity requirements under "Swing Resistance Element." This capacity shows the minimum electric resistance needed to meet the recirculation load. Swing tank volume recommendations are also given, as shown in Figure 12.

Results from the Ecosizer can be downloaded in PDF form, giving the engineer a record of the inputs used and the resulting system.

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Figure 12: Ecosizer recommendations

APPLICATIONS OTHER THAN MULTIFAMILY

Applications deviating from the usage profiles of multifamily housing may need to be evaluated uniquely by using the Ecosizer Custom Hot Water Load feature: www.ecosizer.ecotope.com/sizer/custom_load. Ecotope plans to add ASHRAE load shapes to the Ecosizer in the near future.

The standard Ecosizer software uses a built-in load shape for multifamily buildings. This load shape was developed through years of monitoring multifamily buildings. The Custom Load Shape feature allows the engineer of record to use a different load shape with the same algorithm to size heat pump systems. The engineer can determine a new load shape for the building by using data from the owner, monitoring the building, or using the ASHRAE Applications Handbook (2015).

Engineers should use the "day in which maximum hourly use occurred" in ASHRAE for the custom load shape when sizing HPWH systems. Note that the y-axis in these plots is in gallons per hour per some building characteristic. In the figure below it is gallons per hour per student, but for a food service building it may be in gallons per hour per meal, etc.

Once the load shape is determined, the engineer can input the gallons used for each hour of the day into Ecosizer – Custom Hot Water Load and size the system.

MANUFACTURER SIZING TOOLS

HPWH sizing is much different than gas water heater sizing. Many manufacturers reference the Ecosizer as the preferred sizing methodology to use for sizing systems with their equipment. However, some manufacturers have developed their own sizing methodology to use for configurations not covered in Ecosizer. The project engineers should contact the local representative if they intend to use a manufacturer-specific sizing tool.

IMPORTANCE OF CONSIDERING SYSTEM COP

While it is important to understand the efficiency of the individual pieces of equipment being incorporated into a system, the most important metric a building manager can understand is the performance of a dedicated system as a whole. If an efficient piece of equipment is installed in a system in an inefficient manner, the system will see poor results.

Performance of any particular HPWH is driven by three variables: entering water temperature (EWT), leaving water temperature (LWT), and entering air temperature (EAT). For any given piece of heat pump equipment, it is possible to create a matrix of test conditions varying all three of those variables to create a Performance Map for the product that would indicate the heat output and the required energy input for a range of possible conditions. The Performance Map conditions yield a measure of the equipment COP of the heat pump itself at a range of conditions. The equipment COP does not account for other installation variables that will affect overall performance.

The values for the three key variables that a heat pump will see (EWT, LWT, EAT) are dependent on the climate or conditions where the heat pump is installed and how the system is designed: how the storage is sized and arranged, how the temperature maintenance system is integrated, how any backup capacity is integrated, and how the system is controlled. Further, the overall energy use of the system is driven by the amount and timing of the water demand, and the size of the temperature maintenance load compared to the primary water heating load.

Standard test protocols for mechanical equipment (such as federal and ASHRAE standards) tend to focus strictly on equipment performance and do not effectively address the operational and design characteristics of mechanical systems. While these simplistic test standards can be useful to create a Performance Map of the compressor equipment performance over the range of expected conditions, they do not tell the story of how a given technology will actually perform in the field when control, storage, and recirculation elements are incorporated in the calculations.

The actual metric of interest to designers, owners, policy makers, code officials, and utility programs is Annual System COP (SysCOP). This is the annual energy demand of the entire water heating system (primary water heating plus temperature maintenance) divided by the energy input required. Annual System COP allows for determination of average annual energy use and savings of one system compared to another.

Annual System COP incorporates all major components of a DHW system, including how individual components interact with each other, to determine how efficiently a DHW system may operate. This includes the impacts of technology choice, sizing, piping configuration, controls, and temperature maintenance design. This approach more closely integrates equipment performance and building logistics to determine how efficiently DHW is being delivered.

Several efforts are being employed, including the Advanced Water Heating Specification and California Energy Commission's Performance Code Compliance Approach, that analyze DHW system COP to determine how much energy is used to deliver DHW to building occupants. These approaches rely heavily on DHW plant configuration and equipment selection because they are both drivers of DHW plant efficiency. A high-efficiency, single-pass heater has a great COP on its own, but if the application has a high temperature maintenance load that requires significant electric resistance heating, the entire system isn't very efficient.

Figure 13 illustrates how different system elements may reflect different individual efficiency ratings, compared to the whole system COP metric.

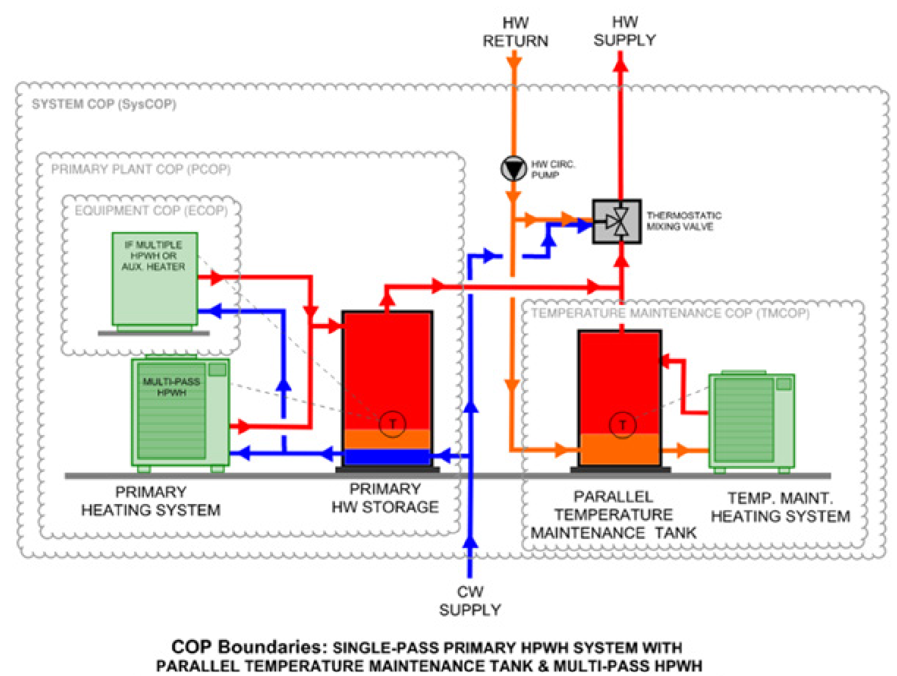

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Figure 13: Elements of equipment and system efficiency ratings

AVAILABLE EQUIPMENT AND CASE STUDIES

The availability of CHPWH equipment is growing rapidly. In the past few years, a number of new manufacturers and new products have entered the market, and more are poised to be released soon. At the same time, demand for this equipment is placing stress on manufacturer production rates, and some manufacturers are limiting the geographical markets in which they offer products. In the near term, equipment availability is likely to be a constraint on the rate of market adoption.

The list of equipment below is current through 2022. Several new products are scheduled for introduction in 2023, and additional manufacturers will be entering the market.

Case studies are available for some of the products identified, with more to be published soon.

MAKE/MODEL	NOMINAL SIZES	REFRIG.	CASE STUDIES
Eco2/SanCO_2	1.25 ton	CO_2	www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/co2-heat-pump-water-heater-final.pdf
Mitsubishi/QAHV	10 ton	CO_2	www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/20220505-mitsubishi-qahv-mv-study-task-3.pdf
Nyle/C250	20-ton	R134	Not Available
Colmac/CxV	5-25 ton	R134	www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/20220222-colmac-cx-mandv-jackson-apts-task17.pdf www.legacy.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Documents/Dec2015%20RCC%20Report%20with%20Appendix.pdf
Lync	20-ton	CO_2	Not Available
Nyle/E-Series	0.7-30 ton	R513	www.bpa.gov/-/media/Aep/energy-efficiency/emerging-technologies/ET-Documents/FINAL-20211020-Nyle-Feasibility-Study.pdf

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