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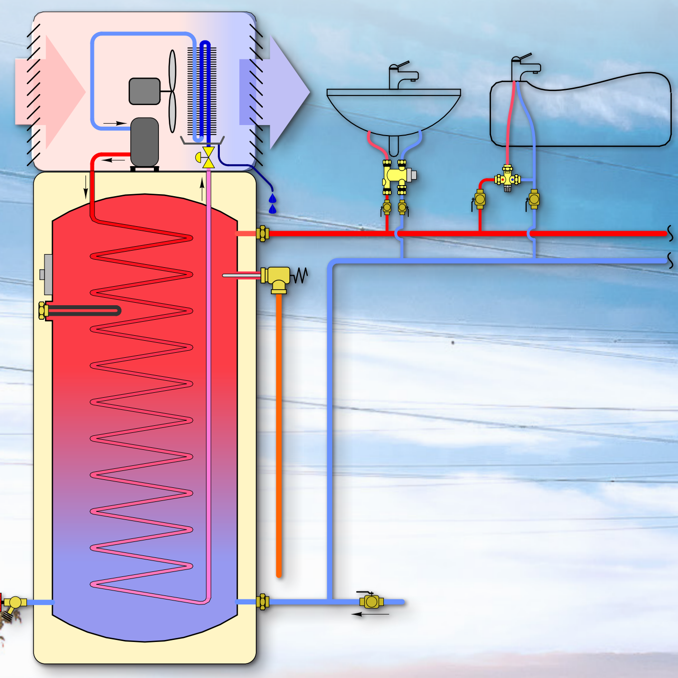
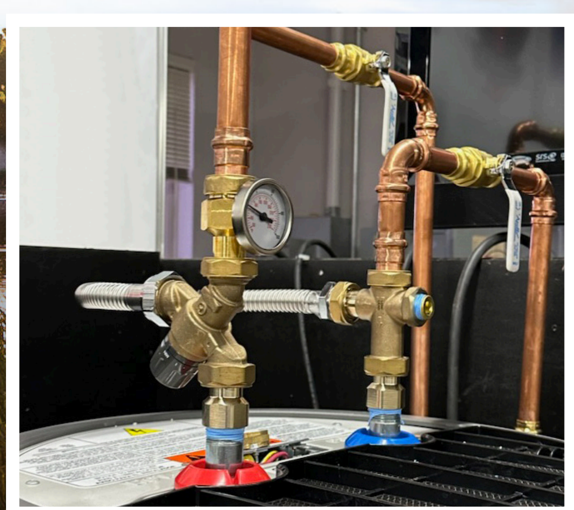
July 2023





Heat Pump Water Heater Fundamentals

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FROM THE GENERAL MANAGER & CEO

Dear Plumbing and Hydronic Professional,

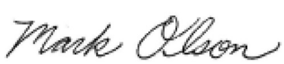
Caleffi ships products to 90 countries around the world. Caleffi North America collaborates with its international colleagues in identifying and developing products that provide cutting edge solutions for our customers as their needs evolve. Our many industry awards for innovation testify to our collective efforts.

In the past two years the transition to heat pump technology has greatly accelerated in both Europe and North America. Although space heating and cooling are the dominant market sectors for heat pumps, their ability to heat domestic water offers the potential to substantially reduce energy use in both residential and commercial applications. But, the path to an all-electric mechanical room is not crystal clear. It is impacted by uncontrollable and often unpredictable geopolitical and economic factors.

At Caleffi, we strive to provide cutting-edge products, technical support, and educational resources to facilitate evolving technologies. Our objective is to work with you to identify the best-case scenarios in a variety of applications that leverage changing market conditions. This issue of idronics discusses the fundamentals and application details for this emerging technology, heat pump domestic water heating systems.

We hope you enjoy this issue of *idronics* and encourage you to send us any feedback by emailing us at *idronics@caleffi.com.* An entire collection of the journal series can be found at *idronics.caleffi.com*.

Mark Olson



General Director & CEO

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A Technical Journal
from
CALEFFI NORTH AMERICA, INC.
3883 W. Milwaukee Rd.
Milwaukee, Wisconsin 53208
USA

Tel: 414-238-2360
FAX: 414-238-2366

E-mail: idronics@caleffi.com
Website: www.caleffi.us

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*Cover installation photo courtesy of Amtrol Inc. West Warwick, RI

1. INTRODUCTION

The two primary objectives in a domestic hot water plumbing system are:

- Heat the water in a cost-effective manner.
- Deliver the water at an appropriate temperature to the plumbing fixtures.

There are many options to accomplish both objectives using a wide variety of energy sources. One approach that is quickly gaining market share is based on heat pump technology. When applied properly, heat pump water heaters (HPWH) require approximately 60% less energy than electric-resistance water heaters and have the potential to reduce carbon emissions when compared to gas water heaters, according to the Pacific Northwest National Laboratory.

There are many opportunities to integrate HPWHs in both residential and commercial domestic water systems. Identifying those opportunities and planning the installation accordingly will maximize energy efficiency without negatively affecting the comfort and convenience consumers expect.

Residential HPWHs typically use an air-to-water heat pump assembly mounted on top of a tank. The condenser coil for the heat pump is either submerged in the tank or wrapped around it. Figure 1-1 shows the concept. Most HPWHs used in residential applications also have auxiliary electric-resistance heating elements that supply heat during periods of high demand.

Figure 1-1

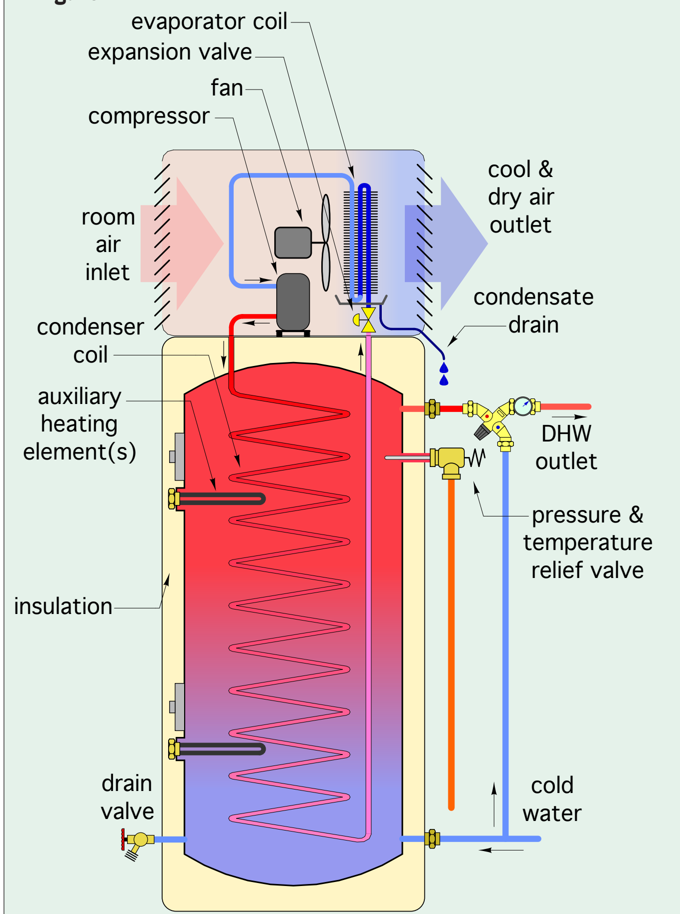
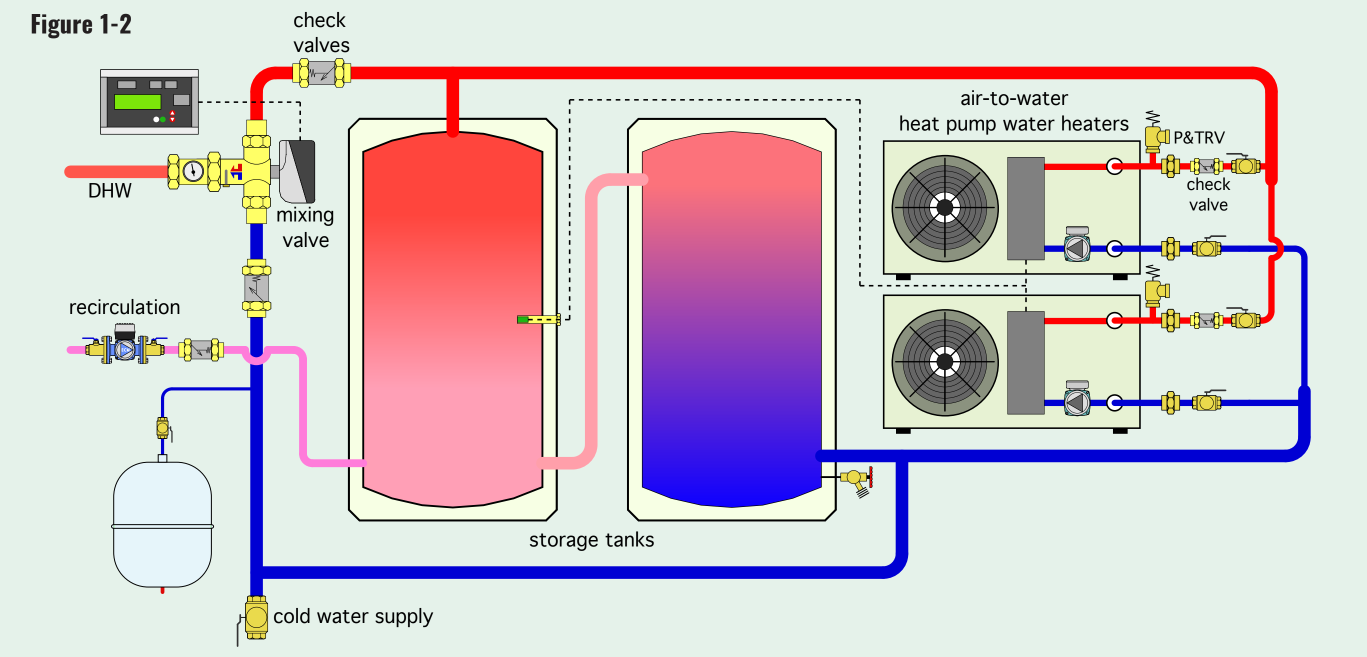


Figure 1-2



In commercial systems, one or more modular HPWHs are connected to one or more thermal storage tanks. Figure 1-2 shows the concept. Separating the storage tanks and heat pump units gives more flexibility to designers and installers when matching load requirements.

Using a standard refrigeration cycle, HPWHs transfer heat from air surrounding them, or sometimes from outside air, into the tank water. Because they mostly *move* heat rather than create it, HPWHs can provide the same amount of domestic hot water as an electric-resistance water heater using only 25 to 33% `of the electrical energy input.

The U.S. Department of Energy and ENERGY STAR® recommend replacing water heaters every ten years. Based on this, the opportunity to reassess the best water heating system for a given building is a relatively frequent recurring cycle. In the average North American home, the original water heating system may be replaced many times throughout the life of the building.

When a building's water heater fails and a replacement is needed as soon as possible, the least complicated approach is a "like-for-like" replacement, since it restores hot water service quickly. However, these ASAP swaps often omit consideration of new technology and energy-saving options.

Changing a standard water heater to a HPWH is best evaluated *before* an emergency. By considering the potential for improvement, owners can achieve highly energy-efficient domestic hot water heating using HPWHs.

There are advantages and limitations to every type of water heating device. The underlying energy-efficiency potential of heat pump technology creates a high potential to save energy in the domestic water heating segment. This issue of *idronics* will assist in evaluating HPWH technology in both retrofit and new construction applications.

2. HEAT PUMP FUNDAMENTALS

REFRIGERATION CYCLE

Nearly all current-generation heat pump water heaters operate on a basic "vapor/compression" refrigeration cycle. During this cycle, a chemical compound called the refrigerant circulates around a closed piping loop passing through all major components of the heat pump. These major components are named based on how they affect the refrigerant passing through them. They are as follows:

- Evaporator
- Compressor
- Condenser
- Thermal expansion valve (TXV)

The basic arrangement of these components to form a complete refrigeration circuit are shown in Figure 2-1.

To describe how this cycle works, a quantity of refrigerant will be followed through the complete cycle.

The cycle begins at station (1) as cold liquid refrigerant within the evaporator. At this point, the refrigerant is colder than the air surrounding the evaporator. That air is generically referred to as the "source media," because it is the source of the low-temperature heat. Because of the temperature difference between them, heat moves from the air into the lower-temperature refrigerant. As the refrigerant absorbs this heat, it changes from a liquid to a vapor (e.g., it evaporates). The vaporized refrigerant continues to absorb heat until it is slightly warmer than the temperature at which it evaporates.

The vaporized refrigerant flows on to the compressor, where its temperature and pressure are increased. The electrical energy used to operate the compressor is also converted to heat and added to the refrigerant. The temperature of the refrigerant gas leaving the compressor is usually in the range of 120º to 170ºF, depending on the operating conditions.

The hot refrigerant gas flows into the condenser at station (3). Here it transfers heat to the "sink media," which is water in a HPWH. As it gives up heat, the refrigerant changes from a high-pressure, high-temperature vapor into a high-pressure, somewhat cooler liquid (e.g., it condenses).

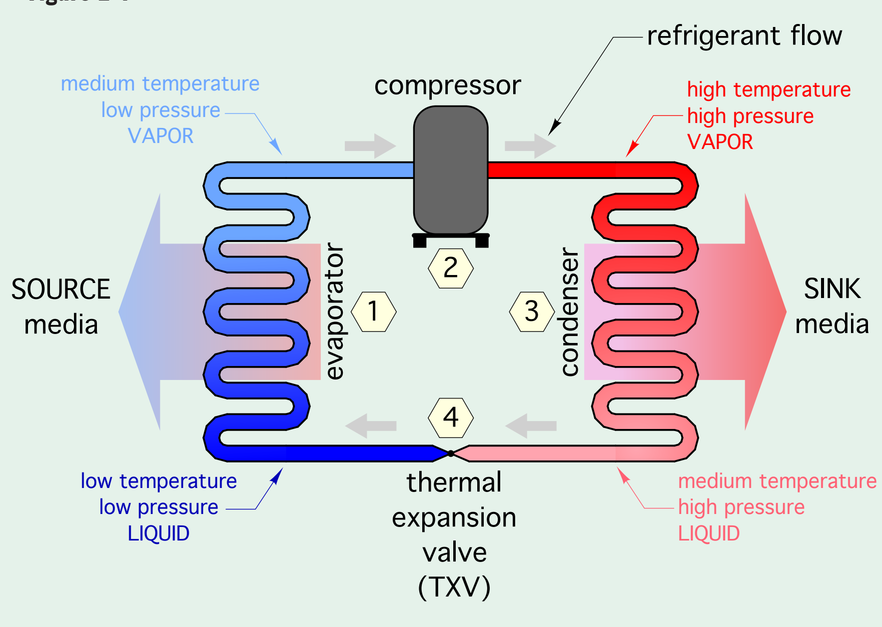
The high-pressure liquid refrigerant then flows through the thermal expansion valve at station (4), where its pressure is greatly reduced. The drop in pressure causes a corresponding drop in temperature, restoring the refrigerant to the same condition it was in when the cycle began. The refrigerant is now ready to repeat the cycle.

The refrigeration cycle remains in continuous operation whenever the compressor is running. In addition to heat pump water heaters, this basic refrigeration cycle is used in many other types of devices such as refrigerators, freezers, water coolers, dehumidifiers, air conditioners, deli cases, vending machines and many types of heat pumps for specific HVAC applications.

Figure 2-2 shows the three primary energy flows involved in the refrigeration cycle. The first energy input is low-temperature heat absorbed from the surrounding air into the refrigerant at the evaporator. The second energy input is electrical energy flowing into the compressor whenever it is operating. The third energy flow is the heat output from the condenser, which is transferred to the water in the storage tank.

The first law of thermodynamics states that, under steady state conditions, the total energy input rate to the heat pump must equal the total energy output rate. Thus, the sum of the rate of heat absorbed from the air surrounding the heat pump water heater, added to the rate of electrical energy input to the compressor, must equal the rate of energy dissipation from the

Figure 2-1



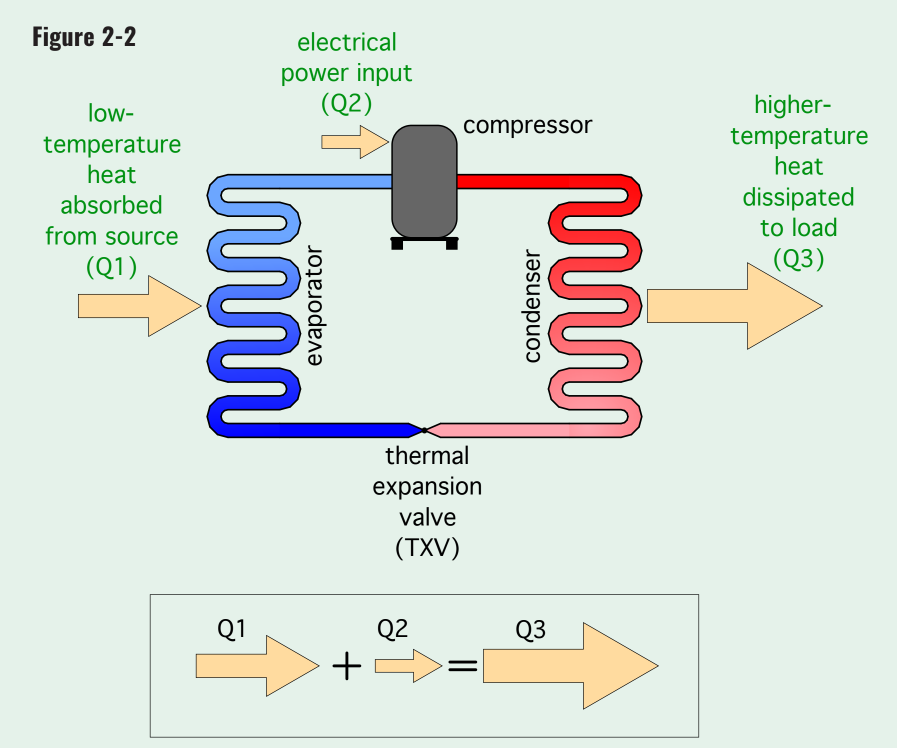


Figure 2-2

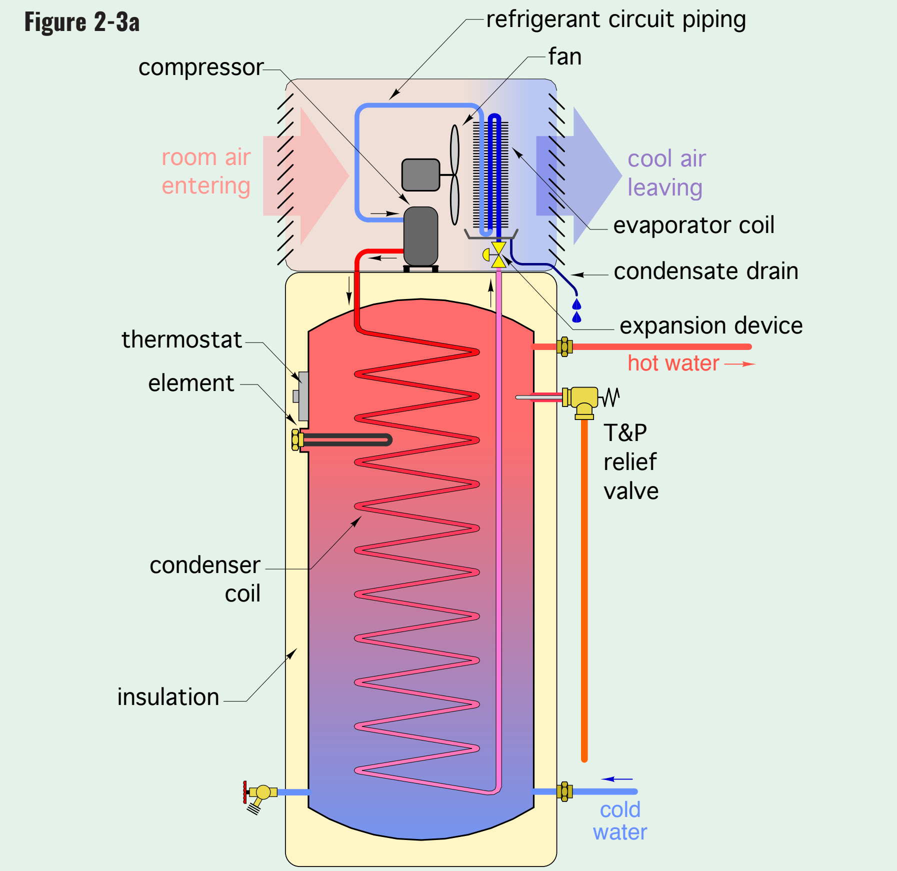


Figure 2-3a

refrigerant at the condenser. This is depicted by the arrows in Figure 2-2.

The basic refrigeration components represented in Figures 2-1 and 2-2 are present in all heat pump water heaters. There is also a fan to blow air across the evaporator coil. The size and placement of these components relative to each other is determined based on the "compartment" into which they must fit, as well as the heating capacity of the heat pump water heater.

In a typical residential class heat pump water heater, most of the refrigeration components are housed in a module that's attached to the top of a tank, as shown in Figures 2-3a,b.

The condenser portion of the refrigeration circuit consists of metal tubing that is either immersed in the tank water or wrapped around and bonded to the outside of the steel water tank. In either case, heat is transferred from the hot refrigerant gas passing through the tubing to the water in the tank.

Figure 2-3b

Courtesy of True Blue Mechanical, Newark, DE

Figure 2-4a

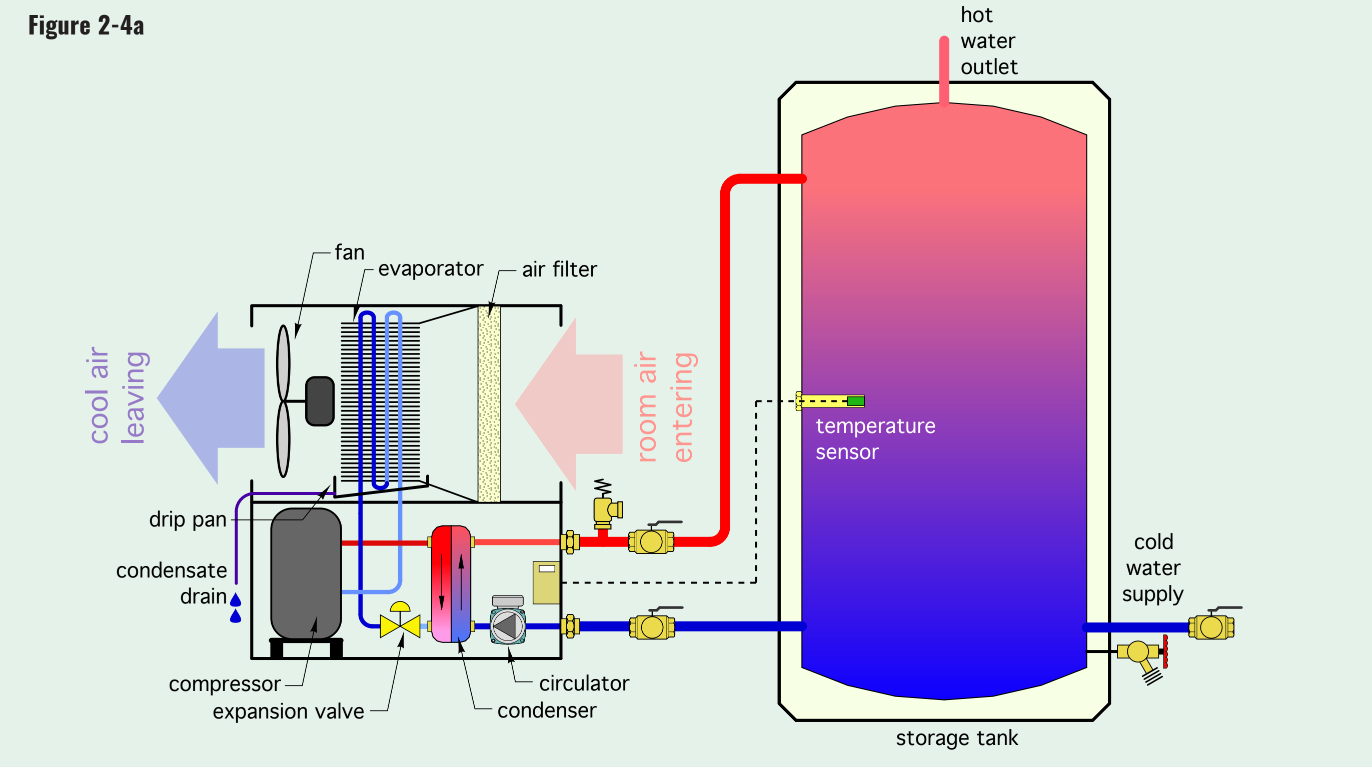
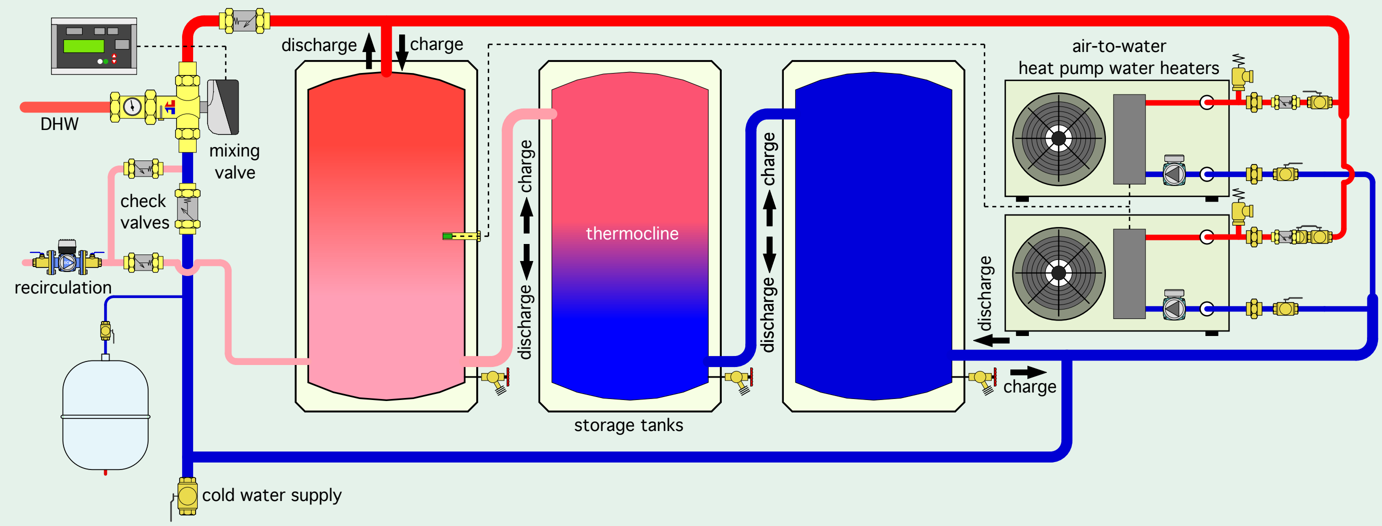


Figure 2-4b



A small fan is used to move air surrounding the unit through the evaporator coil.

Some heat pump water heaters also have serviceable air filters to keep the surface of the evaporator coil as clean as possible. Most residential HPWHs also have one or two electric-resistance heating elements that can provide auxiliary or backup heating if the refrigerant circuit requires servicing.

Commercial-scale heat pump water heaters have larger versions of the basic refrigerant system components but typically do not have an integrated storage tank. The condenser is housed in the same compartment as the other refrigeration system components, and domestic water is circulated between the heat pump and one or more storage tanks. Figure 2-4a shows the concept.

Figure 2-4c

Figure 2-4b shows a configuration where two HPWHs supply three thermal storage tanks. The three tanks are piped in series. This helps create a "thermocline" region that separates the hot and cold water within the tanks. When the heat pumps are running and the flow through them is greater than the demand for domestic hot water, flow through the tanks is from left to right. This supplies the heat pumps with the coolest water in the storage system, which increases their coefficient of performance (COP). When the heat pumps are off, or when flow to the building's hot water distribution system is greater than the flow through the heat pumps, flow through the tank assembly will be from right to left.

Figure 2-4c shows an example of a system piped in this configuration and prefabricated on a skid so that it can be placed as a single unit.

Figure 2-4d shows a commercial system example utilizing a "swing tank" with electrical resistance elements. The main purpose of the swing tank is to supply heat loss from the building's recirculating hot water delivery system.

COEFFICIENT OF PERFORMANCE

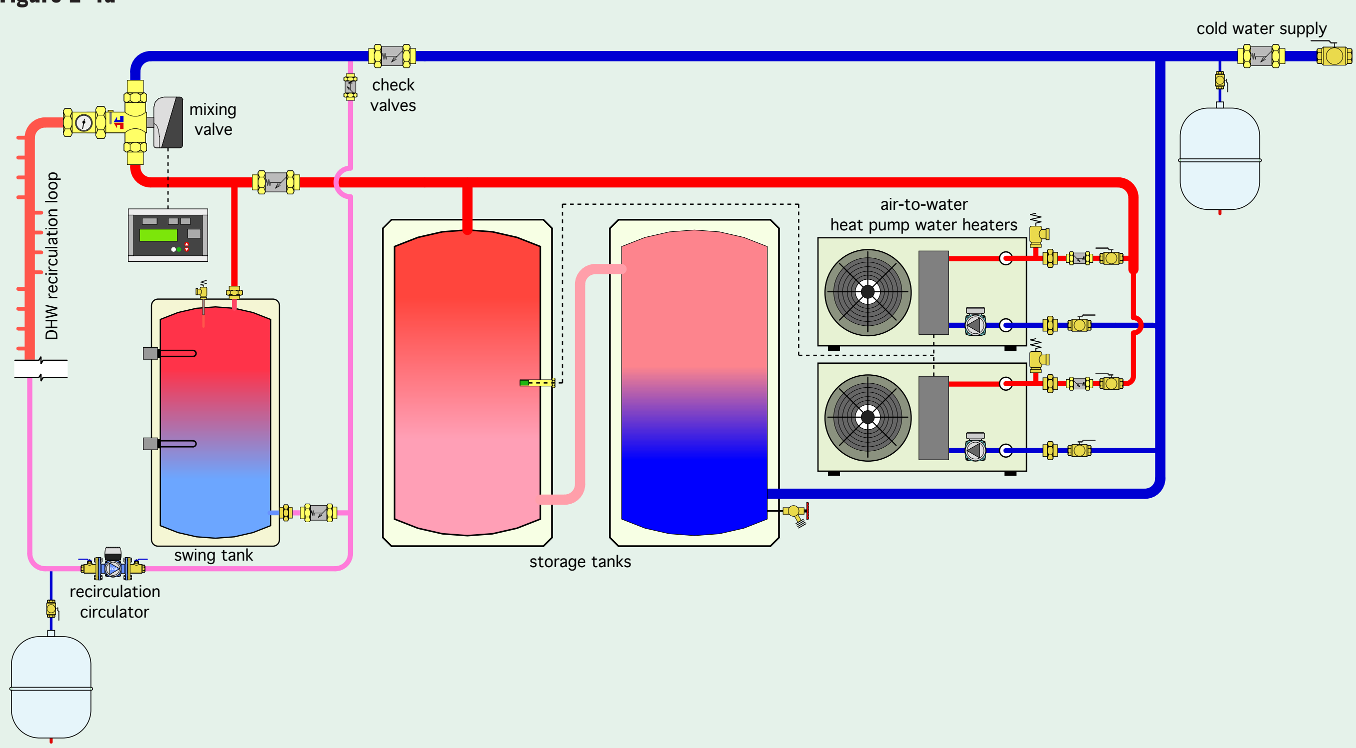
The primary advantage of using a heat pump water heater in comparison to an electric-resistance water heater, is that the majority of the heat added to the water came from the air surrounding the heat pump, rather than being created by an electric-resistance heating element (as it would with a standard electric water heater).

This advantage can be expressed as the coefficient of performance (COP), which in the case of a heat pump water heater can be expressed as follows:

Formula 2-1:

$$COP = \frac{Q_w}{3.413\ (P_e)}$$

Figure 2-4d



Where:
COP = coefficient of performance (a unitless number)
Q_w = rate at which heat is added to water in storage tank (Btu/hr)
P_e = electrical power input to operate water heater (watts)
3.413 = conversion factor to change watts to Btu/hr

For example: Assume a heat pump water heater transfers heat to the water in its storage tank at a rate of 30,000 Btu/hr, while operating with an electrical power input of 2,400 watts. It's COP under this condition would be:

$$COP = \frac{Q_w}{3.413\ (P_e)} = \frac{30,000\frac{Btu}{hr}}{3.413\frac{Btu/hr}{watt}\ (2400watt)} = 3.66$$

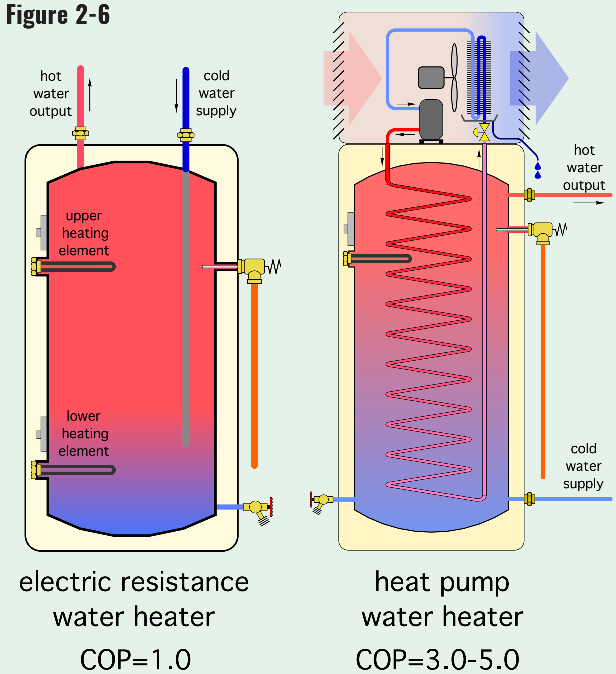
Notice that all the units on the physical quantities cancel out, leaving the COP as a unitless number.

The COP can be interpreted two ways.

1. It can be thought of as a *multiplier* on the rate of heat input to the water compared to the rate at which an electric-resistance heating element, operating at the same electric input power, would add heat to the tank. In this example, the heat pump water heater would be adding heat to the tank at a rate 3.66 times greater than an electric-resistance heating element, when both the heat pump and element are operating at 2,400 watts electrical input power.

2. The COP can also be considered as a *"divider."*

Figure 2-6



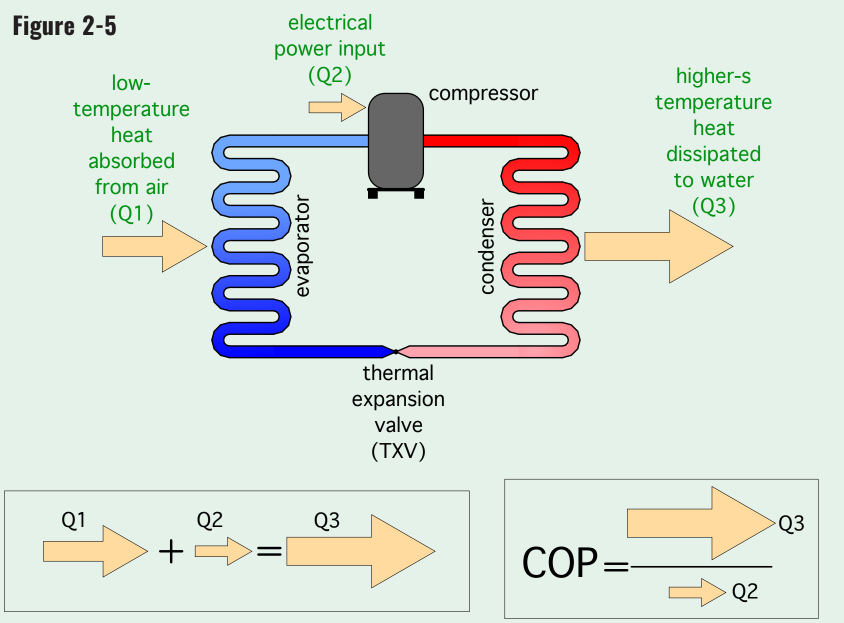
The operating cost of a heat pump water heater running at a COP of 3.66 would be (1/3.66) of the operating cost of an electric-resistance water heater, when both supply the same amount of hot water. This is the primary benefit to an owner paying for hot water service.

Another way to visualize the significance of COP of a heat pump water heater is the ratio of the rate at which heat is added to the water divided by the rate of electrical input to operate the heat pump. Figure 2-5 shows this concept as an extension of Figure 2-2. The large arrow at the top of the ratio represents the rate of heat delivery to the water. The small arrow represents the rate of electrical energy input.

The COP of a heat pump water heater will vary depending on the air temperature from which heat is being absorbed and the water temperature maintained in the storage tank. In general, the warmer the air temperature and the lower the water temperature setting, the higher the COP.

The COP of an electric-resistance water heater is always 1.0. Figure 2-6 shows a comparison between the COP of an electric-resistance water heater and a residential-scale heat pump water heater.

Figure 2-5



3. HEAT PUMP WATER HEATER INDUSTRY STATUS

CURRENT REPLACEMENT MARKET

According to the Advanced Water Heater Initiative (AWHI), *"The two major markets for HPWHs include single family and multifamily residences, which currently house over 118 million water heaters. More than 25 million of those systems are over 10 years old and will need to be replaced in the next five years, providing an opportunity to reduce the carbon footprint of water heating substantially."*

A 2022 report by the U.S. International Trade Commission stated, *"The U.S. HPWH market doubled in the last five years, with apparent sales of Energy Star-certified units increasing from 52,000 units in 2016 to 104,000 in 2020. However, HPWHs account for a relatively small share of the water heater market, with 2020 sales accounting for only 2 percent of the overall market."* While the overall U.S. market share is low, some cities and states will see rapid HPWH growth. As an example, the Washington State Building Code is pursuing heat pumps being required for space heating and water heating in single-family and multi-family new construction projects starting in late October 2023.

ENERGY-EFFICIENCY IMPROVEMENT POTENTIAL

The U.S. Energy Information Administration states that water heaters can account for 19% to 32% of a homeowner's utility bill. Commercially, the percentage of the utility bill will vary drastically, based on the tenants' water-demand characteristics. The financial impact of water heating is significant enough to justify a deeper evaluation of current water heating technology. As of 2020, 59 million U.S. homes used natural gas for water heating and 57 million used electricity. The energy savings potential for modernizing domestic hot water systems is enormous.

CLIMATE CHANGE IMPACTS

An emerging, important factor in the water heater selection process relates to the indirect effects of the energy source used. In the past, water heaters would often be selected based on the most economical, local fuel source. If the building is served by a utility offering low-cost electricity, an electric-resistance water heater would likely be the best fit. If the customer is hundreds of miles away from the closest natural gas pipeline, locally stored propane could be a good fit. However, energy market prices are no longer the only driver for product selection.

A reason HPWHs are favored in climate change mitigation scenarios is that they allow for integration of a bigger mix of renewable energy sources from the local and regional electrical utility grids. If water is heated with gas, the regional source of fuel in the pipeline may change, but the inputs are always the same combustible hydrocarbons.

Figure 3-1

If the source energy for water heating is electricity, it could flow from any mix of fossil-fuel-based or renewable sources across the region.

Decarbonization is a motivating factor in a growing number of jurisdictions across the world. It is defined by the National Renewable Energy Laboratory as: *"no net climate impact resulting from carbon or other greenhouse gasses."* To slow the trend of human-caused climate change, some jurisdictions have incentivized the movement away from machines that produce point-source pollution by burning fossil fuels to machines that do not use these fuel types.

HPWHs help with city and building-level decarbonization efforts, as these machines do not burn fossil fuels within the envelope of the building. They meet the local criteria for decarbonization. However, the decarbonization puzzle is more complex than a single building or city. A single decarbonized building may just be shifting the use of fossil fuels further away, while also adding electrical transmission losses between the power plant and building.

In order to advance a widespread decarbonization effort, the electricity supplied by renewable energy sources must

Figure 3-2

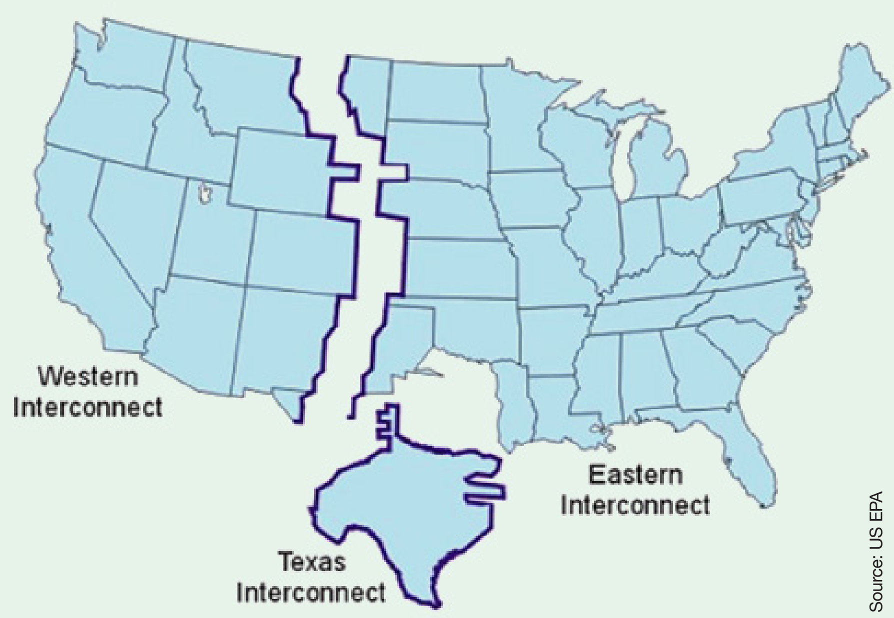
provide a major contribution. Merely switching from gas water heaters to HPWHs will not decarbonize the grid. For decarbonization efforts to be meaningful, the electric utilities must incorporate a larger portion of renewable energy power plants into the grid. Often, a regional electric grid will still have a mix of fossil fuels as part of the overall energy-generation network. The regional-scale decarbonization of the electrical grid is a much bigger topic than can be addressed in this journal.

In Canada, the adoption of decarbonized water heaters is on a faster trajectory. Across Canada, carbon emissions are taxed at an increasing rate, per ton of CO_2 emissions. Vancouver is an example of a city that is phasing out natural gas service to new buildings. Essentially, the status quo of consuming fossil fuel-based energy for DHW will be increasingly expensive. The policies currently in effect, or on the horizon, will require consumers to either pay the carbon tax or pay to install more energy-efficient water heating systems.

From a policy perspective, there is a parallel in the U.S. automotive industry. Federal and state energy-efficiency standards are pushing car and truck manufacturers to increase the average miles-per-gallon of gasoline efficiency in their fleets. Most major car companies are phasing in hybrid gas/electric and all electric automobiles quickly, as a way to comply with these benchmarks.

While energy policy is likely not the major decision point for automobile buyers, increased competition in the electric car segment has led to an increased number of less-expensive options for electric vehicles, spurring competition. According to the Edison Electric Institute, in the U.S., *"It took eight years to sell 1 million electric vehicles and fewer than three years to sell the next million."* Time will tell if policy-driven decisions will push HPWHs to a similar adoption trajectory.

Figure 3-3 North American Electric Power Grids



Not all jurisdictions are pushing for decarbonization. According to the American Council for an Energy-Efficient Economy, in some U.S. States, consumers are discouraged from disconnecting their current gas service. The rationale is often related to concerns that shifting gas water heaters to electric would increase the potential for brownouts within an already overloaded electrical grid. As an example, a utility company may be forbidden from providing financial incentives to customers who want to disconnect gas service and switch to electric-resistance heating, cooling and water heating technologies unless specific criteria are met.

There are three energy grids in the United States: western states, eastern states and Texas. The eastern and western grids are able to share electricity regionally to better avoid brownouts and incorporate a large mix of power plant technologies. Texas is an islanded electrical grid. While the Texas interconnect is independent of the other states and is able to determine the ideal power plant mix, there are significant strides to be taken at the grid level to accommodate HPWHs and electric cars if customer demand moves in that direction.

For decarbonization to be an effective long-term solution for water heating it must dispel the concern that it will overwhelm the grid. Modernization of the electrical grid is an important step to reduce waste and improve reliability. Best practices in domestic hot water delivery will help deliver an energy-efficient and reliable future.

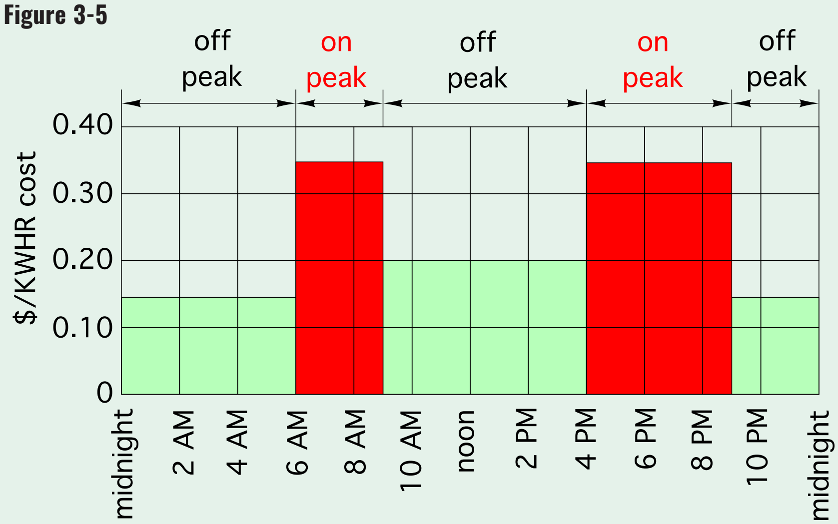
FINANCIAL INCENTIVES

In the United States as of January 2023, ENERGY STAR-eligible water heaters purchased and installed between 2023 and 2032 are eligible for a tax credit of 30% of the installation cost, up to $2,000. Local governments and utility companies may offer additional incentives. Verifying eligibility for financial incentives is an important factor for HPWH adoption and may help offset some of the costs associated with a changeout of a water heater. Depending on utility costs and usage rates, HPWHs might still have the lowest lifetime costs without rebates. DSIREUSA.org is a zip code-based search engine to help find current rebate information.

ELECTRICAL SERVICE UPGRADES

New Buildings Institute research found: *"A typical house that is built before the last 10 years will mostly have an electric service panel size of 100-150 Amps. More than 100 million households in the U.S. are in this category. Smaller electric service panel sizes and amperage services worked fine with fossil fuel-fired appliances. That may not be the case as we switch the market to electrification of the buildings."* Upgrading the electrical service to buildings that are moving to HPWHs may be a prerequisite to installation and can be costly. Product selection, related to input voltage requirements, and water storage temperature set points are two variables that can potentially reduce the electrical panel upgrade requirement. These are discussed later in this journal.

Figure 3-5



EQUIPMENT MANUFACTURER CHANGES AND REQUIREMENTS

The U.S. Department of Energy's ENERGY STAR® program administers water heater energy-efficiency standards. Specific ENERGY STAR certification is required for products to qualify them for rebates or by the local authority having jurisdiction for use in new construction. There is enormous leverage to steer the water heating market based on these standards. As an example, "low nitrous oxide (NOx)" emissions were a benchmark for gas appliances. Subsequently, "ultra-low NOx" emission requirements were enacted. In the future, ENERGY STAR could adopt "zero NOx" requirements, which would effectively exclude all gas appliances from receiving the certification. In the current trajectory, water heater manufacturers are working diligently to ensure they have a wide range of HPWH product offerings to stay ahead of the curve.

Figure 3-4

ELECTRICAL GRID INTEGRATION AND DEMAND RESPONSE

Electrical grid brownouts are often cited as a discouraging factor for a transition to HPWHs. A brownout is a period of time where the demand for electricity exceeds grid capacity and the voltage to end-users drops, often below the minimum threshold for proper, consistent equipment performance. A blackout is where grid voltage in an area drops to zero. If all of the gas water heaters in North America were rapidly replaced with electric heat pumps, there is a high likelihood that the grid would not be able to handle the increased electrical demand, resulting in brownouts during periods of high demand.

Similar to charging an electric car overnight, HPWHs can integrate with the grid and avoid heating water during peak electrical demand periods. In many regions of the world, demand for electricity is high in the morning and throughout the late afternoon and evening. These are the times when people are getting ready for work and arriving back home.

In the conceptual example shown in Figure 3-5, a utility company charges different prices for electricity depending on the time of day. Essentially, if customers can avoid using excess electricity during peak periods, they will pay less for the same amount of energy. Scheduling electrical appliances to start, operate or charge during the non-peak times is possible and advisable with current technologies and consumer behavior changes.

Specific to water heating, industry stakeholders are developing a load-shifting communication protocol originally called EcoPort, now the CTA 2045 technical specification. This is a unified communication technology that allows utility companies to react to demand trends by sending a signal to CTA 2045-enabled water heaters, thus shedding some of the electrical load for a period.

As an alternative, non-grid-connected option, water heaters can be scheduled with different setpoints during the day to reduce the amount of water heating cycles during known peak times of day. Point-of-distribution mixing valves can be used to ensure a consistent delivery temperature to occupants in systems where the storage temperature fluctuates, as detailed in the next section.

The HPWH industry is quickly evolving. Globally, the demand for more energy-efficient methods for heating domestic water is rising. For a variety of reasons, HPWHs will gain market share in the years to come. The next section will describe the general evaluation process to determine how to best utilize HPWH technologies.

4. EVALUATING WHEN A HEAT PUMP WATER HEATER MIGHT BE A GOOD FIT

NEW CONSTRUCTION INSTALLATIONS

Imagine that an architect, engineer and installer coordinated their efforts to construct a building with a HPWH in mind, as if it were a priority for integrated design. In a new construction setting, there would be fewer constraints when determining the size and location for infrastructure such as water service entrances, electrical panel placement, floor drain locations, size of the mechanical room and communication subsystems.

Under such ideal conditions, what would the design and installation team do to set up the HPWH for the best performance? This section discusses several considerations.

WATER HEATER LOCATION

One early consideration in the design process is the physical location of the heat pump and storage tank. In new construction, an ideal location would be a mechanical space with good access to equipment that is in close proximity to the loads supplied by that equipment.

In moderate climates, a portion of a home's garage space is often reserved for mechanical equipment, including the water heater. Garages provide convenient access for service and eventual replacement of water heaters. They also have lower potential for damage should a leak develop. Many garages have floor drains. Garages are also common points of entry for water and electrical services. The concrete floors in most garages can easily support the weight of residual water heaters, and when necessary, can be designed to handle much higher loads associated with large or multiple thermal storage tanks.

The mechanical space should allow for routine equipment service. HPWHs require service clearances for all tank connections, electrical access points, air filters, controls and refrigeration system components. Water heater manufacturers typically specify a minimum space requirement to install and service their equipment.

Figure 4-1

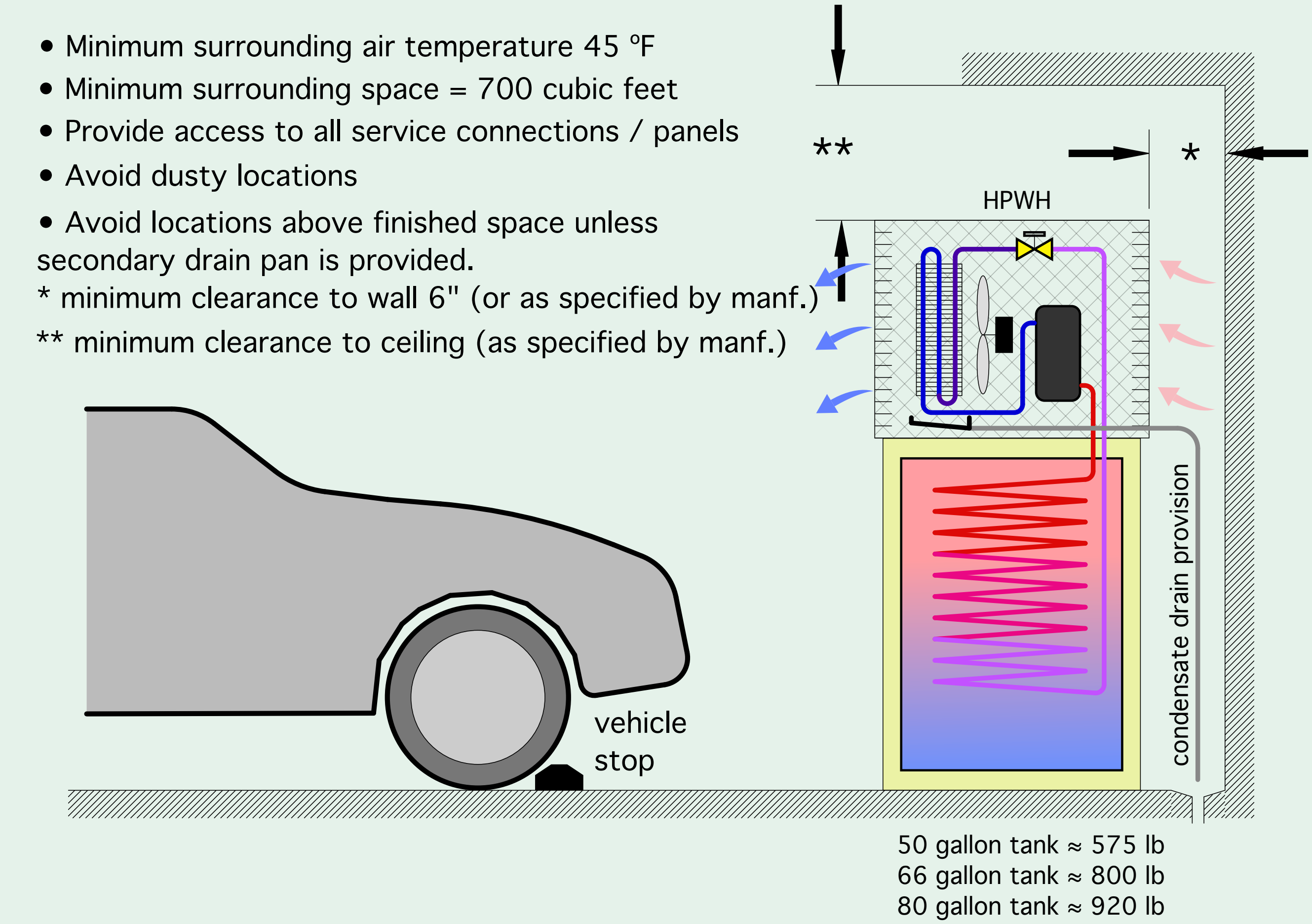


Figure 4-2

Guidelines for space surrounding HPWHs (verify with specific manufacturer)

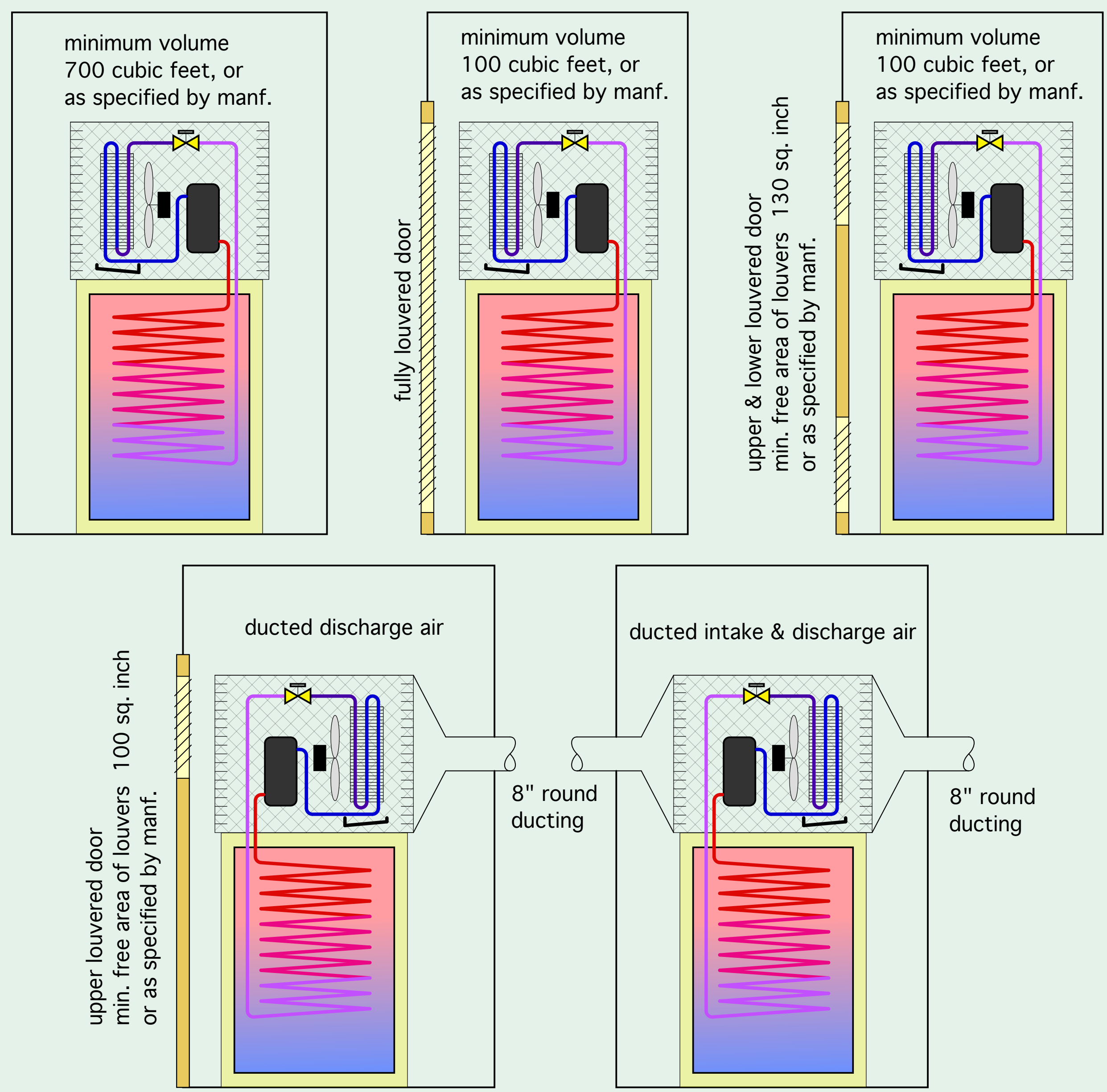


Figure 4-1 shows and lists several considerations when planning the location of a typical residential heat pump water heater. Always consult with the authority having jurisdiction for local compliance, as well as equipment manufacturers for specific installation requirements

Fuel type can also dictate location. Gas water heaters require access to a gas service line and the ability to vent the products of combustion. Gas water heaters also are constrained by the maximum allowed length for vent piping. Nearly all codes require gas-fired water heaters that are located in garages to be on elevated platforms to prevent contact with gasoline or other fuels that might be spilled on floors.

Electric-resistance water heaters and HPWHs do not have the constraints associated with fuel supply and venting for gas-fired water heaters. They have an installation advantage in that they can often be located in relatively small closets or under sink vanities.

HPWHs need more space based on their airflow requirements. This is a major prerequisite for proper performance. If a HPWH is installed in the same space that would have been used for a similar-sized electric-resistance water heater, it could drastically limit performance.

An ideal location for a HPWH would be in the middle of a large interior space that maintains itself at or close to normal indoor temperatures. However, this is seldom possible because building space is expensive, and most occupants would much rather locate mechanical equipment in the smallest and least usable space within a building.

In many cases, water heaters are placed in minimally heated mechanical spaces that are separated from occupied spaces. These locations minimize noise transmission to occupied spaces and keep the equipment out of sight. Most HPWHs can be so located, provided that adequate airflow and surrounding air temperatures are ensured.

There are ways to provide for adequate airflow, while still partially enclosing the HPWH. Common options for self-contained residential HPWHs include the following:

- A large space having a minimum volume determined by HPWH size and manufacturer, with unobstructed airflow to the unit.
- A closet installation with a fully louvered door or a combination of upper/lower louvers, per manufacturer requirements.
- Inlet/outlet ducting to another space or outside, similar to a gas appliance.

Figure 4-2 shows some of these options. Different HPWHs have specific airflow and placement requirements set by their manufacturers. Such requirements take precedence over the conceptual guidelines shown in Figure 4-2.

SOURCE OF ABSORBED HEAT

There are situations in which a HPWH placed in a conditioned space absorbs heat supplied by a furnace, boiler or heat pump used to heat that space. Effectively, the space heating system is providing most (or all) of the heat absorbed by the HPWH. While the wire-to-water efficiency of the HPWH might be excellent based on absorbing "surplus" heat not specifically generated for space heating, the *net efficiency* of using a HPWH decreases when absorbing heat generated by another device for space heating.

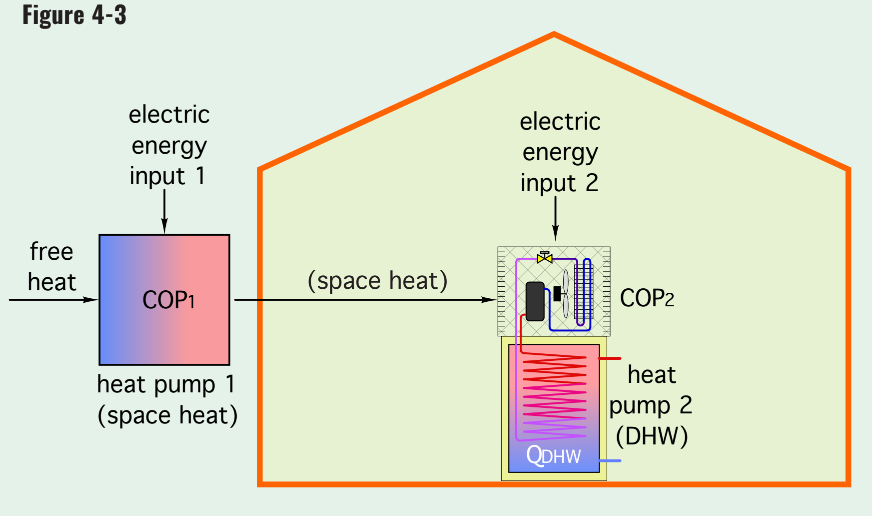
Examples of "surplus" heat include low-grade heat in outdoor air, excess solar heat gains inside a building, low-grade heat in an unconditioned basement or garage, or heat generated by equipment or processes in a commercial building. These sources of heat are a *byproduct* of how the building is configured or used, rather than heat intentionally produced by the building's heating system.

Figure 4-3 shows the concept of "cascading" heat pumps (e.g., where the HPWH absorbs heat placed in its vicinity by another heat pump).

Heat pump 1 is absorbing free heat from outside the building, combining it with heat derived from electricity, and sending that heat inside the building. Heat pump 2 is a HPWH. It absorbs heat that was placed inside the building from heat pump 1, combines it with more electrical energy, and sends combined energy into domestic water within the tank.

The net COP of this cascading heat pump system can be determined:

Figure 4-3



Formula 4-1

$$COP_{net}=\frac{\left(\frac{COP_1}{COP_1-1}\right)\left(\frac{COP_2}{COP_2-1}\right)}{\left[\left(\frac{COP_1}{COP_1-1}\right)\left(\frac{COP_2}{COP_2-1}\right)-1\right]}$$

Where:

COP_{net} = the overall COP of the two cascaded heat pumps

COP_1 = the COP of the space heating heat pump (must be > 1.0)

COP_2 = the COP of the heat pump water heater (must be > 1.0)

Note: To use this formula, both COP 1 and COP 2 must be > 1.0

For example, if a heat pump provides space heating to a building while operating at a COP of 4.0, and a heat pump water heater within that building only absorbed heat produced by the space heating heat pump while operating at a COP of 3.0, the net COP, defined as the heat added to the domestic water divided by the total electrical input to enable that heat placement, would be:

$$COP_{net}=\frac{\left(\frac{COP_1}{COP_1-1}\right)\left(\frac{COP_2}{COP_2-1}\right)}{\left[\left(\frac{COP_1}{COP_1-1}\right)\left(\frac{COP_2}{COP_2-1}\right)-1\right]}=\frac{\left(\frac{4}{4-1}\right)\left(\frac{3}{3-1}\right)}{\left[\left(\frac{4}{4-1}\right)\left(\frac{3}{3-1}\right)-1\right]}=\frac{2}{2-1}=2.0$$

A net COP of 2.0 means that for every two units of heat delivered to the domestic water, one was absorbed from a "free" source, and the other came as electric heating. Although this net COP is still double the COP of any form of electric-resistance heating (e.g., COP = 1.0), it is far lower than the rated COP of the heat pump water heater operating under the assumed condition of absorbing "free" surplus heat.

In most buildings, there will be times when the heat absorbed by the heat pump water heater is indeed surplus heat, and thus the long-term net COP will likely be higher than the above calculation implies. Still, the concept of "cascading heat pumps" shown in the previous example demonstrates that placing a HPWH within the heated thermal envelope of a low-energy or net-zero building, where the majority of the heat it absorbs is present due to operation of a space heating heat pump, doesn't yield the savings often expected for HPWHs. In such cases, it could be more efficient to configure a domestic water heating subsystem as an ancillary load to the space heating heat pump. Section 5 shows some options for such configurations.

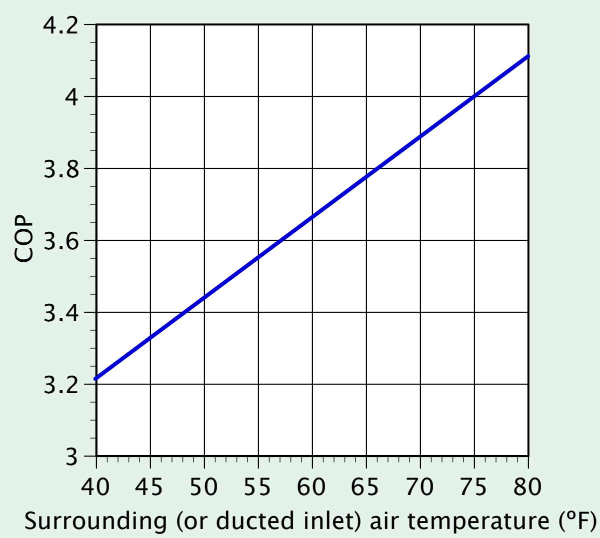
HPWHs always cool the space around them. This must be considered if the space is intended for normal human occupancy. A HPWH located close to an office or living area may cool that space to uncomfortable temperatures, especially during cold weather. Conversely, a HPWH can also create beneficial cooling and dehumidification of spaces that otherwise may be too warm or damp.

Noise is another placement consideration. All water heaters make some noise, and those sounds are perceived differently among occupants. For some, the clicks of a relay in an electric water heater might be annoying, while others may dislike the drone of a HPWH fan or gas appliance blower. Whenever possible, it is best to avoid placing any mechanical equipment, including HPWHs, adjacent to bedrooms, offices or other spaces that are intended to remain quiet. Many hours of design and installation labor can be required to relocate or otherwise address mechanical equipment after it has been installed without regard to the sound it creates, which often leads to complaints from occupants. The ability to duct the airflow required by HPWHs to and from locations away from occupied spaces can help alleviate thermal discomfort and noise issues.

COLD CLIMATE CONSIDERATIONS

As with any heat pump, the coefficient of performance (COP) of a HPWH depends on the temperature of the material from which heat is being absorbed. For most HPWHs, this is the temperature of the air surrounding the heat pump or ducted to it. Figure 4-4 is representative of this effect.

Figure 4-4



The coefficient of performance of a HPHW located in a cold garage or unconditioned mechanical space will be lower than if the same unit was located in a warmer area, such as a server room. At times of high domestic hot water demand, some HPWHs will also activate their electric-resistance heating elements to ensure adequate hot water delivery. This further decreases average efficiency. However, even at lower COP operating conditions, the HPHW uses significantly less electrical energy in comparison to a standard electric-resistance water heater.

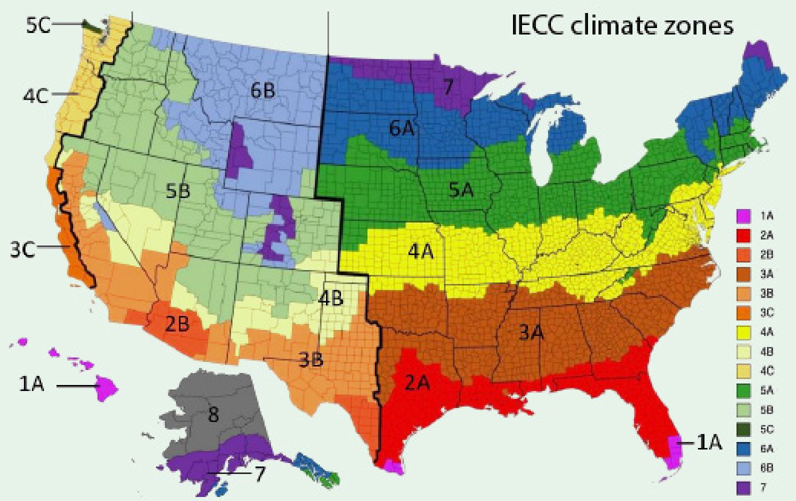
It is also important to avoid installation locations where the water in piping leading to or from a HPWH could potentially freeze, especially during a prolonged power failure.

Figure 4-5

	1 - 3	4A, 4B	4C	5	6 - 7
Basement	👍	👍	👍	👍	👍
Garage	👍	👍	👍	⚠	🚫
Interior Room	👍	👍	👍	👍	👍
Uninsulated Room	👍	🚫	⚠	🚫	🚫

If it's normal to install other types of water heaters in garages where you live, you can put a heat pump water heater there too.

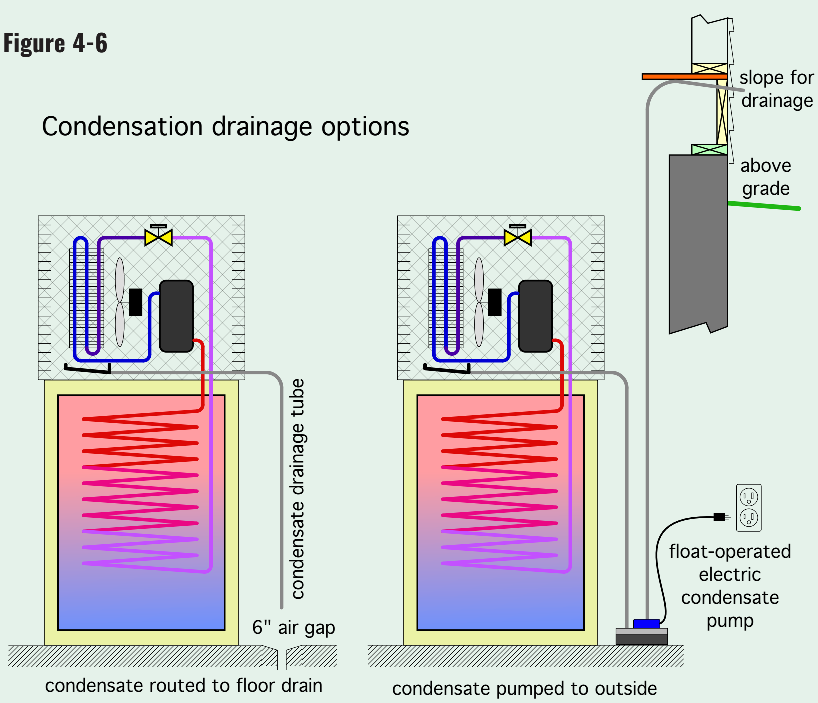
During the coldest months of the year the heat pump may struggle to keep up with demand. Getting a larger tank can help efficiency and comfort.



Courtesy of NEEA

Figure 4-6

Condensation drainage options



The Northwest Energy Efficiency Alliance (NEEA) provides guidance for HPWH installation locations, related to International Energy Conservation Code (IECC) climate zones across the U.S. The map in Figure 4-5 is useful to identify installation location possibilities and should be used in conjunction with HPWH manufacturer guidelines and local building codes.

CONDENSATE MANAGEMENT

All HPWHs create condensate. It forms whenever the temperature of their evaporator coil drops below the dewpoint of the air passing across it. The condensate is not acidic, as is the condensate from a fossil fuel boiler. There is no need for a condensate neutralizer. However, the condensate must be routed to a suitable drain.

A floor drain in reasonable proximity to the HPWH is ideal. If a floor drain is not available, a small automatically operated condensate pump, such as used for residential air conditioning systems, can be used to route the condensate to another drain or outside the building. In the latter case, the condensate drain tube should end above grade and be sloped to avoid freezing in winter.

ELECTRICAL POWER SUPPLY

In new construction, planning to supply a HPWH with 240V power provides the most flexibility for equipment selection. While 120V HPWHs are available, they are best suited for retrofits, or situations where 240V power is not available or would be costly to supply. The use of 240V also reduces amperage and wire size. Larger commercial HPWHs generally require 3-phase power.

Locating the HWHP relatively close to a building's electrical service panel, or a suitable sub-panel, reduces installation cost. The wire type and size used to supply the HPWH is generally specified by its manufacturer. All electrical materials and methods must also conform to local codes.

TANK SIZE

The volume of the storage tank in a HPWH is an important selection consideration. Larger storage volumes typically increase the amount of hot water the unit can deliver, based on the unit's first hour rating. One downside to a larger tank is increased standby heat losses, which increase cost of operation without providing a benefit for building occupants. Additionally, larger storage can increase the installed cost of the system. The balance between ideal water storage volume and heat pump output will vary by project. In Figure 4-7a, a system is designed with a larger heat pump and minimal storage. In Figure 4-7b, a system is sized with larger storage but a smaller HPWH. Both are acceptable designs. Consult with heat pump manufacturers for specific sizing guidance.

Figure 4-7a

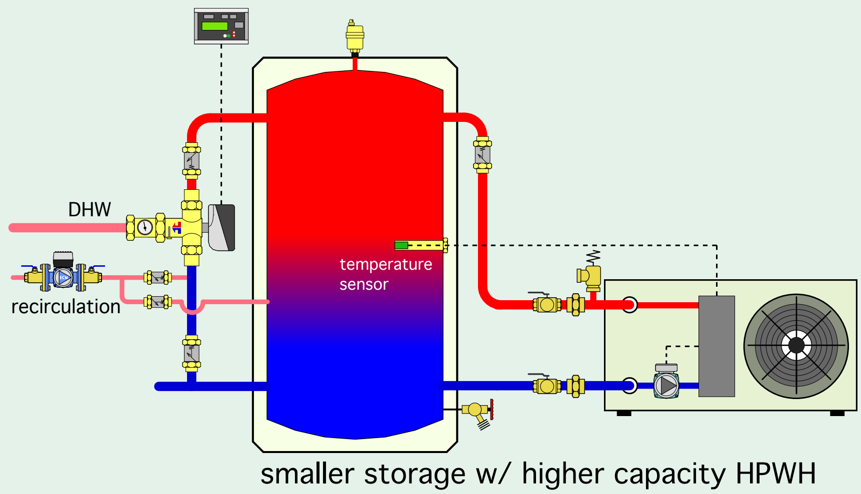
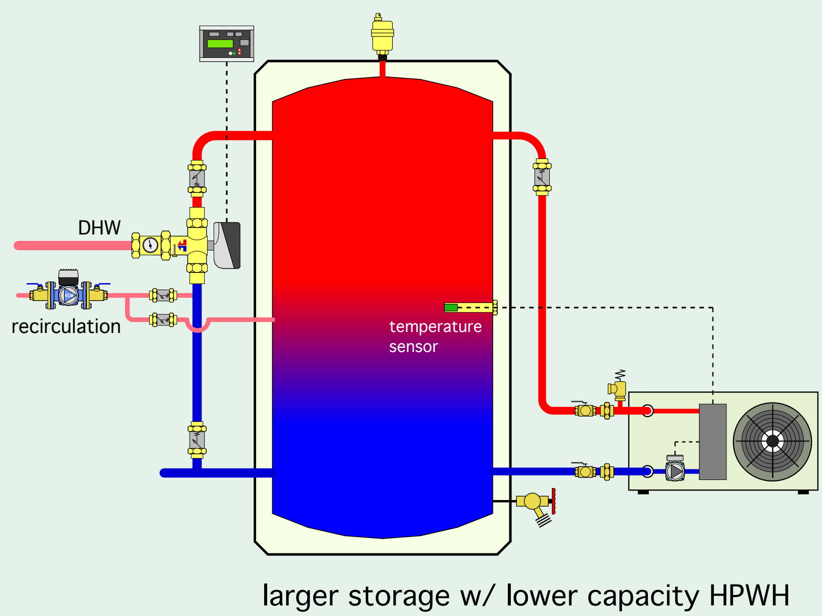


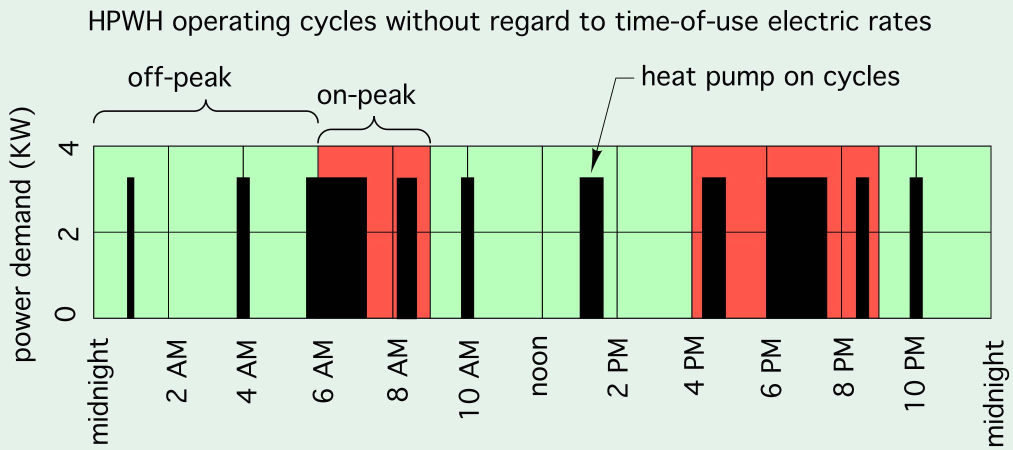
Figure 4-7b



STORAGE TEMPERATURE AND POINT-OF-DISTRIBUTION MIXING VALVES

All HPWHs have an adjustable water temperature setting. Increasing the storage temperature of a water heater increases its ability to deliver hot water to the building. It may

Figure 4-8



also allow for a smaller tank. In some installations, the minimum storage tank temperature may also be mandated based on avoiding Legionella bacteria growth.

Point-of-distribution mixing valves are highly recommended whenever the temperature setting of the water heater is above 120ºF, or higher than otherwise allowed by code or other applicable regulations.

Two different types of mixing valves can be used in systems with elevated storage temperatures. Point-of-distribution (POD) mixing valves listed to ASSE 1017 are designed to deliver consistent water temperatures to the building's plumbing system by mixing hot and cold water. These devices are designed for high flow rates. They are not scald protection devices. Point-of-use (POU) mixing valves listed to ASSE 1070 are designed to prevent scalding at the fixtures.

Point-of-distribution mixing valves are a useful, adjustable part of a HPWH system. It is easier and typically less expensive to add a POD mixing valve, or adjust the temperature setting of such a valve, than to install a larger HPWH, especially if an electrical service upgrade is required for the latter.

Point-of-distribution mixing valves allow the tank temperature to be set higher or for the tank temperature to fluctuate while maintaining a consistent and safe outlet temperature.

Here are three of the most common design options for consideration:

1. Baseline example, fixed temperature setpoint. No point-of-distribution mixing valve.

2. Elevated fixed setpoint. Point-of-distribution mixing valve is added to lower the outlet temperature, effectively adding heat storage capacity without increasing the size of the tank.

3. Variable setpoint. Scheduled to avoid peak utility rates or coordinate with real-time utility information. A point-of-distribution mixing valve is added to lower the mixed outlet temperature, effectively adding energy storage capacity without increasing the size of the tank.

Design option 1 is typical in many water heater installations, especially new construction projects. A simple aquastat or tank sensor calls for heat when the water temperature in the tanks drops slightly. When the tank rises slightly above the setpoint temperature, the call for heat ends. The temperature of water delivered to the building fluctuates slightly, within the temperature differential of these on/off cycles. Often, the differential is small and remains unnoticed by building occupants. No point-of-distribution mixing valve is used, but point-of-use ASSE 1070 may still be recommended (or required) by local codes or regulations.

Figure 4-8 shows a conceptual cycling pattern for the HPWH.

The mathematical area of the black rectangles represents electrical energy input to the HPWH. Notice that much of the energy input occurs during peak electrical rate periods. The length of the on-cycle is determined primarily by the demand for hot water at fixtures.

An advantage of this control method is that it is simple and requires the minimum amount of components. A disadvantage is that it does not take advantage of time-of-use utility rates. Based on typical residential usage, most of the electrical energy used by a HPWH falls within the peak time-of-use utility rate windows. For utilities offering time-of-use electrical rates, the cost of electrical energy supplied

Figure 4-9a Conceptual variation in water temperature for HPWH operating cycles using elevated storage temperature during off-peak periods combined with point-of-distribution mixing.

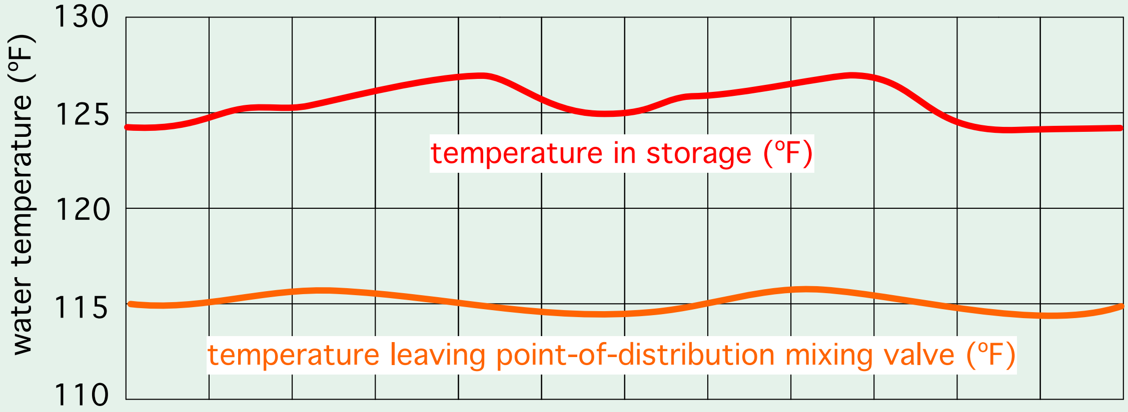
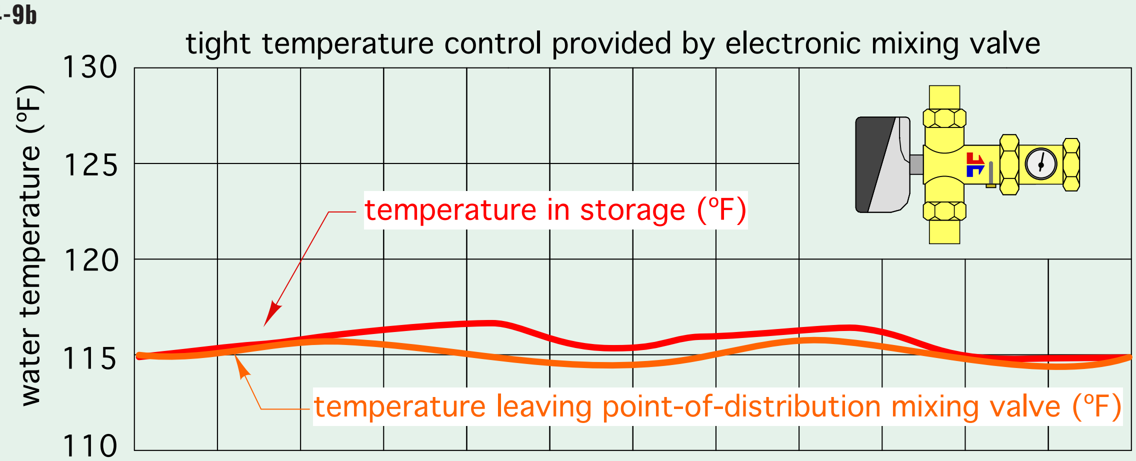


Figure 4-9b



during peak demand periods is often substantially higher than during off-peak times.

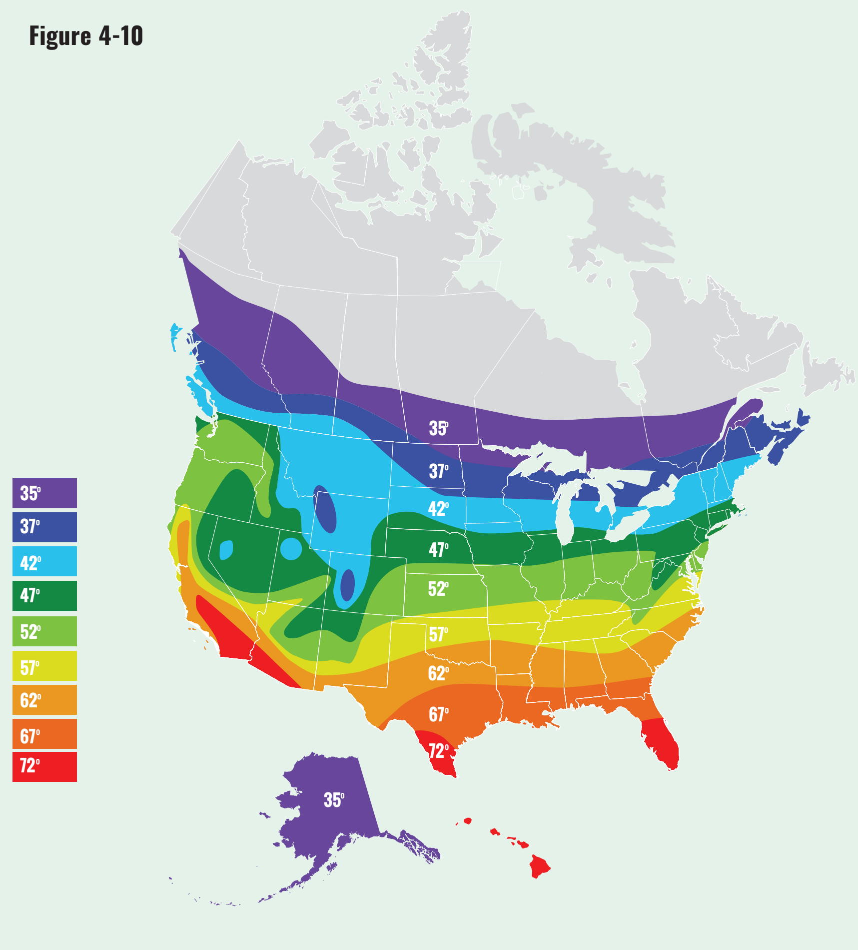
This type of loading is also a concern for utilities that are trying to decarbonize their energy offerings. For example, if all the gas-fired water heaters were switched to HPWH systems operating primarily during peak demand times, utilities would face major overloading, possibly leading to brownouts or other large-scale grid reliability issues.

Design option 2 adds a point-of-distribution mixing valve between the HPWH hot water outlet and the domestic hot water fixtures. The tank water is stored at a higher temperature than the baseline design option 1. An advantage of this scenario is that the higher storage temperature increases the tank's hot water delivery capacity without increasing tank size. The mixing valve provides a safe and consistent temperature to the fixtures throughout the day. A disadvantage is that the COP of the HPWH is slightly reduced when operating at higher water temperatures.

In Figure 4-9a, the HPWH setpoint is higher than the temperature required at the fixtures. The difference between these temperatures is constrained by the minimum temperature difference required between the hot inlet and the mixed outlet of a mixing valve.

Some point-of-distribution mixing valves, typically electronic mixing valves, do not have minimum temperature

Figure 4-10



difference requirements between the hot inlet and mixed outlet streams. An example of this would be a ball-control, element style electronic mixing valve. This is advantageous because the storage temperature does not necessarily have to be higher than the desired hot water delivery temperature. During periods of heavy DHW demand, this approach can maintain a consistent delivery temperature while extracting more heat from the tank.

OPERATING THE HPWH AT HIGHER STORAGE TEMPERATURE

How does the warmer storage temperature boost the effective hot water delivery capacity of the system? As an example, consider a project being designed for Atlanta, Georgia.

Start by determining the average groundwater temperature from the map in Figure 4-10.

For Atlanta, the average groundwater temperature is 62°F. Assume that this is the cold-water temperature supplied to the water heater.

The heat stored in a tank-style water heater can be determined using Formula 4-2a.

Formula 4-2a:

$$H = 8.33(v)(T_s - T_c)$$

Where:
H = heat stored in tank water (Btu)
8.33 = Btus required to raise 1 gallon of water 1°F
V = tank volume (gallons)
T_S = average temperature of stored hot water (°F)
T_C = cold-water inlet temperature (°F)

Consider a 60-gallon tank maintained at an average temperature of 120°F. The heat stored in this tank's water would be:

$$H_{120} = 8.33(60)(120 - 62) = 28{,}988\,Btu$$

If the average storage temperature was increased from 120°F to 130°F, the heat stored in the same tank would be:

$$H_{130} = 8.33(60)(130 - 62) = 33{,}986\,Btu$$

The percentage increase in stored heat would be:

$$\frac{H_{130}}{H_{120}} = \frac{33{,}986\,Btu}{28{,}988\,Btu} = 1.172 \approx 17\% \text{ increase}$$

This increase can be approximated using the chart in Figure 4-11a.

The heat storage formula can be simplified and generalized to determine the ratio of stored heat for any average storage temperature relative to any baseline condition and any tank volume, as given by Formula 4-3:

Formula 4-3:

$$\frac{H_s}{H_b} = \frac{T_s - T_c}{T_b - T_c}$$

Figure 4-11a

% Increase in Water Heater Capacity*									
Storage Temp	Incoming Water Temperature (°F)								
	35°	37°	42°	47°	52°	57°	62°	67°	72°
130°F	12	12	13	14	15	16	17	19	21
140°F	24	24	26	27	29	32	34	38	42
150°F	35	36	38	41	44	48	52	57	63
160°F	47	48	51	45	59	63	69	75	83
170°F	59	60	64	68	74	79	86	94	104
180°F	71	72	77	82	88	95	103	113	125

*baseline 120°F

Figure 4-11b

% Increase in Water Heater Capacity*									
Storage Temp	Incoming Water Temperature (°F)								
	35°	37°	42°	47°	52°	57°	62°	67°	72°
130°F	12	12	13	14	15	16	17	19	21
140°F	24	24	26	27	29	32	34	38	42
150°F	35	36	38	41	44	48	52	57	63
160°F	47	48	51	45	59	63	69	75	83
170°F	59	60	64	68	74	79	86	94	104
180°F	71	72	77	82	88	95	103	113	125

*baseline 120°F

Where:
T_S = average storage temperature (ºF)
T_b = baseline storage temperature (ºF)
T_C = cold-water inlet temperature (ºF)

For example, assuming the same 62ºF cold-water temperature, the ratio of heat stored in a tank with an average water temperature of 140ºF, relative to a baseline average storage temperature of 120 ºF, would be:

$$\frac{H_s}{H_b} = \frac{(T_s - T_c)}{(T_b - T_c)} = \frac{(140-62)}{(120-62)} = 1.345 \approx 34.5\% \text{ increase}$$

This increase could also be approximated using the chart in Figure 4-11b.

If the temperature were increased to 140°F, it would add 34% to the effective capacity. This would essentially make a 60-gallon water heater, storing water at 140°F, deliver the same amount of hot water in a parallel drawdown as an 80-gallon tank storing water at 120°F. The space-saving and cost-reducing potentials of this approach are significant. It also can allow for better demand response scenarios with electrical rates.

In design option 3, the setpoint of the tank changes depending on the time-of-use rates. Essentially, the tank is being used as a rechargeable thermal battery. It is “charged” with extra heat during “off-peak” periods of low electrical demand, with the intent of delivering the stored thermal energy during “on-peak” periods, and thus reducing the load on utilities during periods of high electrical demand. It’s analogous to eating a big meal before leaving the house to minimize the amount of expensive vending machine snacks required before lunch.

Figure 4-12 shows the concept. The mathematical area of the black rectangles represent the electrical energy supplied to the HPWH. Notice that the majority of this energy is supplied during the off-peak periods (approximately 85% of the total daily energy). The width of the rectangles increases, indicating longer heat pump on-cycles, especially ahead of the oncoming on-peak periods. This “packs” more heat into the storage tank.

Figure 4-13 overlays the HPWH cycles with the conceptual temperatures of stored water and the hot water delivered to the fixture through a point-of-distribution mixing valve. An ASSE 1017 point-of-distribution mixing valve allows for consistent water delivery even when the tank is at higher temperatures. The cycle scheduling is controlled through an automated communication protocol with the electrical

Figure 4-12

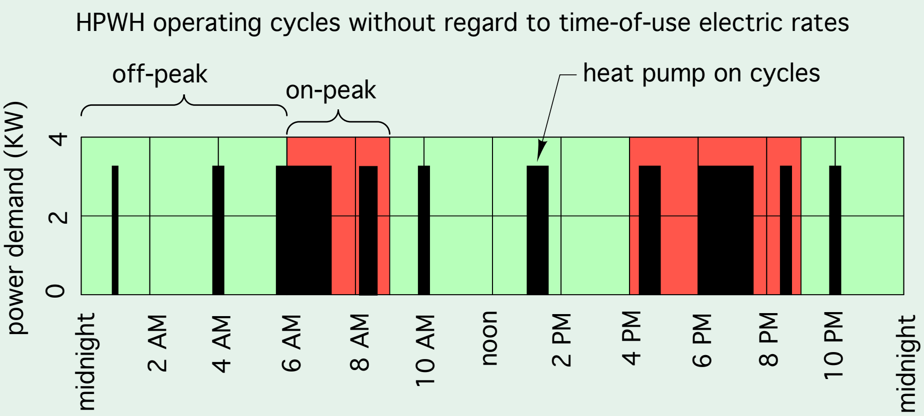
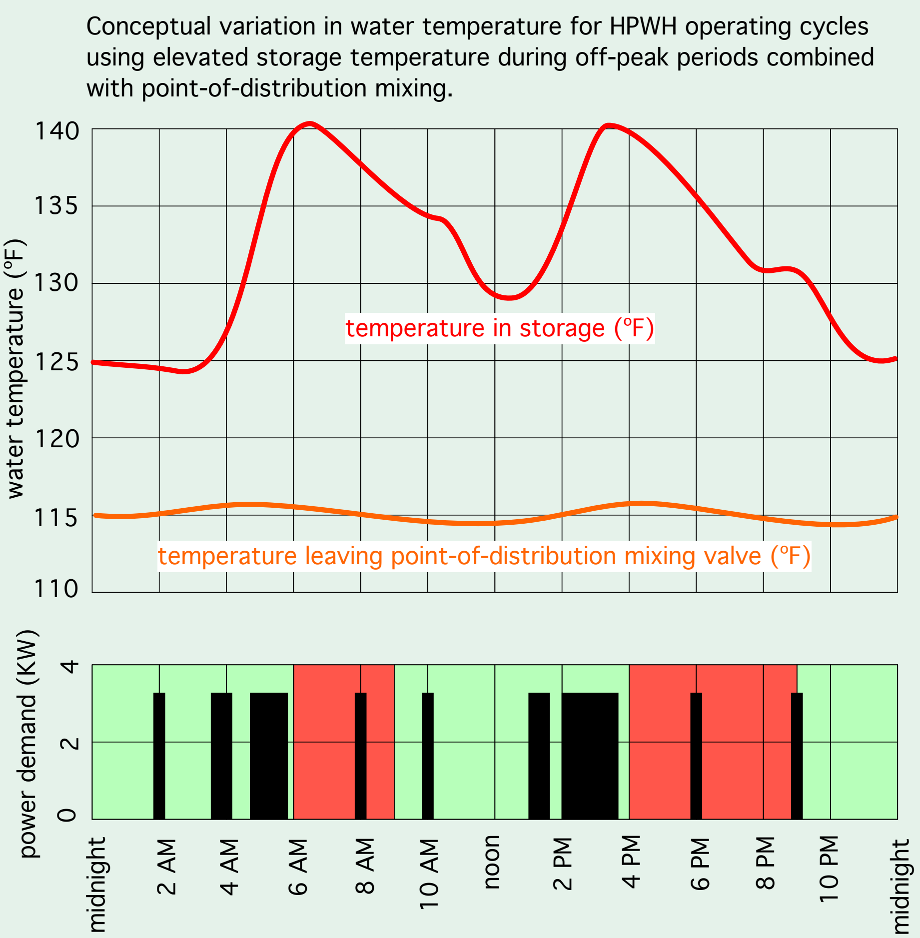


Figure 4-13



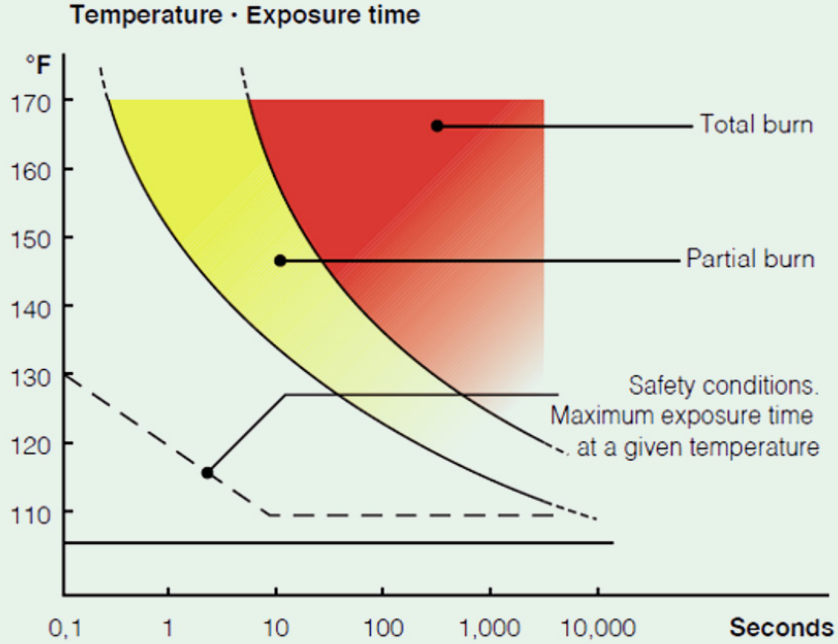
utility. The goal is to minimize electrical demand during on-peak times. This has the combined effect of reducing operating cost to the building owner, while also benefiting utility load management efforts.

The downside of storing water at an elevated temperature relates to maintenance, standby heat losses and the COP of the HPWH. The higher the temperature at which water is stored, the faster the scale will accumulate on heat exchangers and DHW components like thermostatic point-of-distribution mixing valves. Elevated temperatures also lead to faster galvanic corrosion, making anodic protection more vital. Higher storage temperatures increase standby heat loss from the tank and decrease the COP of the heat pump water heater.

As an alternative to external point-of-distribution mixing valves, water heater manufacturers can design their equipment with ASSE 1082 or 1084 compliant technologies to limit the point-of-distribution temperature. These technologies can be used in place of an ASSE 1017 point-of-distribution mixing valve. ASSE 1070 point-of-use mixing valves could still be required, depending on the jurisdiction.

See *idronics #22* for more information on mixing valve applications, point-of-use or point-of-distribution valves

Figure 4-14



POINT-OF-USE MIXING VALVES

ASSE 1070 valves are temperature-limiting devices designed to protect end-users from hot water scalding. They are also designed to prevent the flow of water from the mixed water outlet in the event of the failure of hot or cold supply. The size of the valve is generally smaller than a point-of-distribution valve because it is required to stop the flow of hot water quickly. Unlike a point-of-distribution mixing valve, the point-of-use valves are designed to protect a single fixture or a small group of fixtures.

The maximum allowable hot water distribution temperature varies from one jurisdiction to another based on plumbing

Figure 4-15a

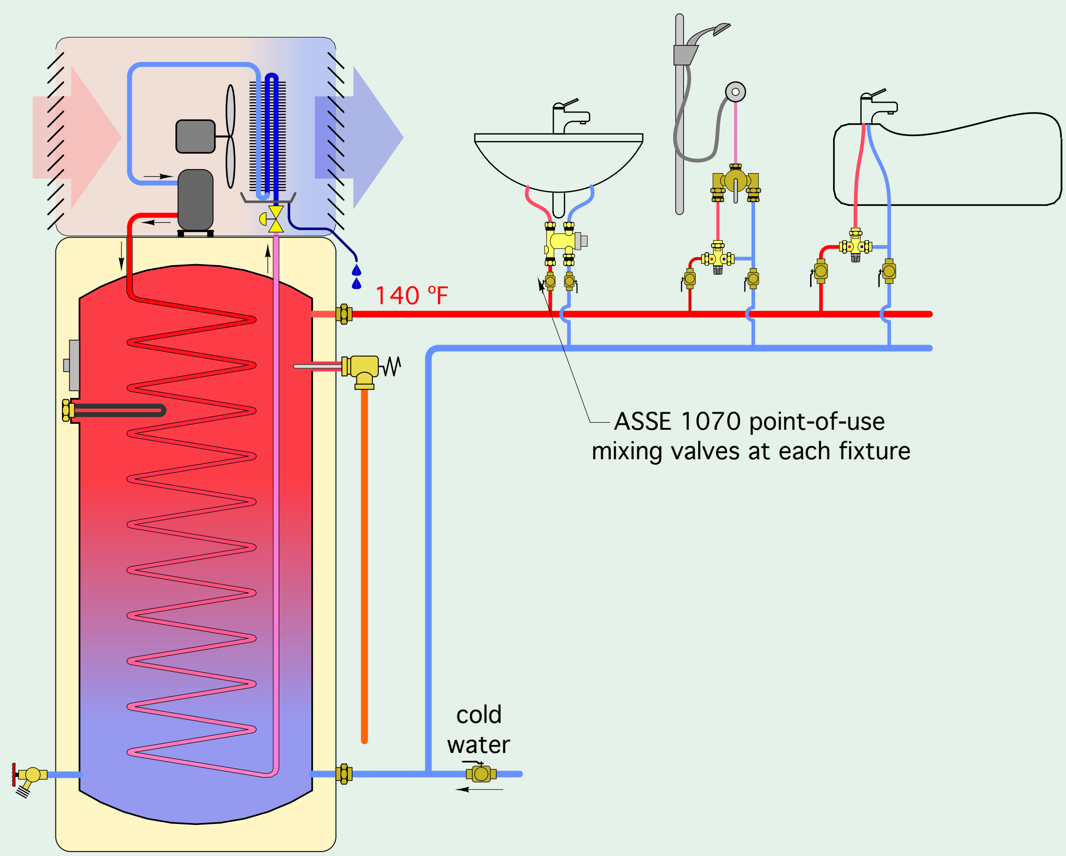
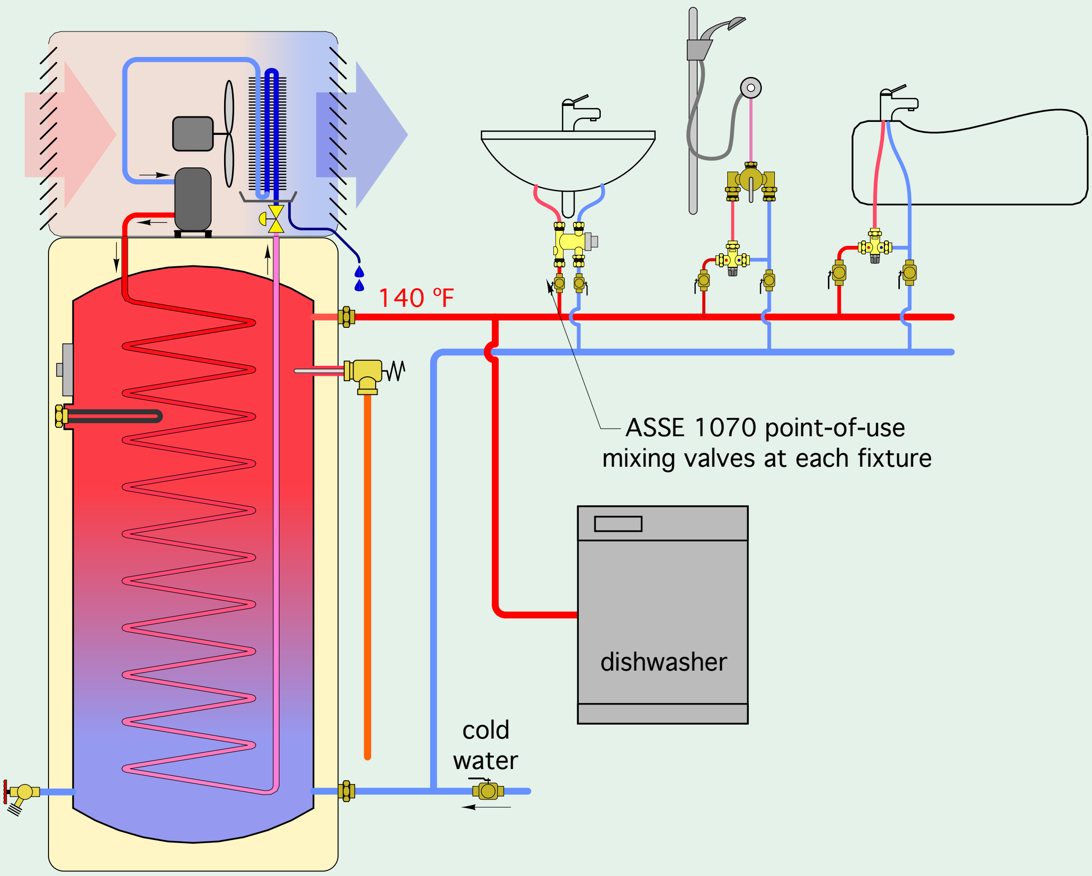


Figure 4-15b



codes or other regulations. Occupant safety is always the primary concern upon which these codes or regulations are based. Scalding can occur quickly, as shown in Figure 4-14.

In some HPWH applications, a point-of-distribution mixing valve is not used. The temperature of the stored water may be elevated above a desired (or mandated) maximum delivery temperature. In these situations, point-of-use mixing valves should be used at each fixture or small grouping of fixtures, as shown in Figure 4-15a.

It is also possible to send water at higher temperatures to a dedicated load, such as a dishwasher, while still using point-of-use mixing for all other fixtures, as shown in Figure 4-15b.

DOMESTIC HOT WATER RECIRCULATION

In an ideal domestic hot water delivery system, heated water emerges from a faucet the moment it is opened. There would be no wait for cooler water to be purged from the piping ahead of heated water delivery. This desirable condition can be closely approximated through use of a recirculating domestic hot water delivery system.

There is an important balance to establish in recirculating domestic hot water systems: minimizing wait times for hot water at the fixtures while not wasting energy in the recirculation loop. In concept, DHW recirculation increases the total heat loss from the hot water delivery system. Holding the heated water in a well-insulated storage tank, rather than distribution piping, reduces heat loss and the excessive cycling of the water heater. However, omitting DHW recirculation systems may result in extended wait times for hot water at fixtures, which is undesirable and also leads to excessive water waste.

Poorly designed or inadequately insulated hot water recirculation systems can create unnecessary cycling of water heaters, thus wasting energy. This effect is potentially more noticeable in systems using HPWHs due to their reduced heating capacity/recovery rate relative to gas-fired water heaters. This is especially true during periods of high hot water demand or in systems with excessive heat loss from a recirculating piping loop.

In some situations, hot water recirculation to all fixtures is not justified. As an example, if a warehouse has a single mop sink located far from the water heater, a small, dedicated point-of- use water heater at the sink would save installation time and cost. It would also reduce energy losses compared to circulating hot water over long distances.

See *idronics #21* for more information on balancing valve applications for DHW recirculation.

RETROFIT HEAT PUMP WATER HEATER INSTALLATIONS

This section discusses factors that need to be considered when adding a heat pump water heater to an existing system.

Based on a mix of workforce development, new HPWH technologies, rebate programs, energy standard advancements and other factors, a 2022 Progress Report by the Advanced Water Heater Initiative projected 30% HPWH market share scenario by 2028. *Retrofit application flexibility is key*, because a majority of the water heater market is for the emergency replacement of failed water heaters. While planning for the best-case new construction installation of a HPWH was discussed in the previous section, additional considerations need to be made for retrofit installations. Every installation location is different. As is the case in all field-installed mechanical systems, some site conditions may be ideal, while others may be limiting. Prefabrication is an excellent option for commercial retrofit systems, as shown in Figures 4-16a,b.

Figure 4-16a

Courtesy of Small Planet Supply, Tumwater, WA

Figure 4-16b

Courtesy of Small Planet Supply

WATER HEATER LOCATION

In a retrofit, the location of the water heater is sometimes predetermined; however, a thorough assessment of the location needs to be made before replacement work begins. The basic requirements for airflow, electrical capacity, service clearances and condensate drainage need to be verified. If one or more of these prerequisites cannot be met with reasonable cost and complexity, it is better to use another type of water heater rather than compromise the performance of the HPWH. In scenarios where a HPWH is not utilized, there is still opportunity to update mixing valves, balancing valves and add insulation to improve the performance of the system.

In some residential installations, there is an opportunity to move the water heater from the original location to a new space. Often a garage in a residential application is a good fit for a relocation in a milder climate. However, the distribution piping and components might also need to be relocated, increasing installation cost. Always check the manufacturer installation manuals when determining acceptable locations.

AIRFLOW

HPWHs need an adequate supply of air to operate at peak performance. In a retrofit application, this could mean "unboxing" the mechanical space. When replacing existing water heaters that were installed in closets or small mechanical spaces, verify the minimum volume of the space with the HPWH manufacturer's requirements. If the minimum volume is not met, one possibility is to add louvers to the mechanical room doors. A few ideal locations for louvered doors would be in an adjacent exterior hallway/atrium that has solar gains from windows or in a computer server room that may have a high cooling load. A few undesirable location examples would be louvered doors connecting to bedrooms, offices or living spaces where occupants may be impacted by the cool air leaving the HPWH or by the sounds of the equipment.

Because it creates the potential for condensation, avoid ducting a HPWH system to an attic. A general recommendation is to terminate the ductwork outside the building envelope.

When replacing a gas water heater with a HPWH, there may be existing ductwork for supplying combustion air. That ducting may be reusable for a HPWH installation, depending on the diameter and total equivalent feet of the ductwork.

An advantage of using ducted outside air for a HPWH is that the absorbed heat is coming from outside the building envelope. This reduces the possibility of thermal discomfort near the equipment. A downside to outdoor ducting is the added installation time and cost. It is also important to consider that if only the exhaust air from the HPWH is ducted outside, a negative air pressure could be created in the space, drawing more outside air through the building envelope.

The main decision points for ducting outside air to the HPWH relate to climate. In a high alpine environment, the COP of the HPWH may be significantly lower if ~40°F air is the source of absorbed heat. Ducting supply air from the outdoors in a warm climate may lead to a higher COP, compared to absorbing heat from the cooler, conditioned air within the building.

Equipment service clearances should also be checked. Avoid installing HPWHs in areas that generate considerable dust (e.g. a basement woodshop). The dust will quickly accumulate on the filter screen. If the screen is not frequently cleaned, the performance of the heat pump will decrease due to reduced airflow. If the screen is removed, the dust will accumulate on the evaporator coil where it would be difficult or impossible to remove.

Installers should also ask owners about any issues related to their current water heater when considering a HPWH. For example, does the current system create objectionable noises or does it take a long time for hot water to reach certain fixtures when first used in the morning? These insights help guide placement of a replacement water heater in a way that minimizes or eliminates undesirable existing issues.

CONDENSATE

Ideally, the condensate produced by a HPWH would flow by gravity through a pipe to a suitable drain. When this isn't possible, one option is to install a condensate pump that would collect and expel any condensate produced by the HPWH. There may also be a possibility of connecting the condensate drainage tube from the HPWH to a condensate drainage pipe or pump that serves an existing air conditioning system or other type of heat pump.

PIPING

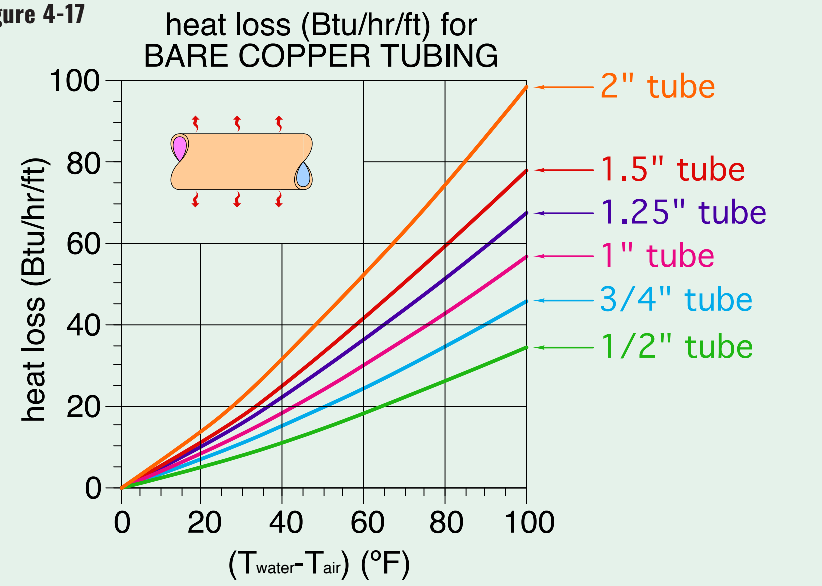
Installers should examine the piping to an existing water heater to determine if improvements can be made at the same time as the water heater replacement. The issue of wasteful DHW recirculation piping in existing buildings will not be remedied by replacing the existing water heater with a HPWH. A poor DHW recirculation system may be revealed when a HPWH is installed, if not accounted for in the retrofit work. With any equipment upgrade, reassessing pipe insulation, mixing, balancing and other componentry is critical. Additionally, the cost and complexity of making changes to the hot water distribution system will often be lower if done at the same time the water heater is replaced.

The heat loss of an existing recirculation loop should also be evaluated to determine next steps in a retrofit. This is especially important with HPWHs because if the heat loss of the recirculation is similar to the output of the HPWH when in heat pump only mode (as opposed to hybrid mode, where electrical resistance heating is also operating), the heat pump might need to operate whenever the recirculation pump is on.

It is important to know the rate of heat loss from a recirculating DHW loop. The following example demonstrates that this is a relatively easy calculation.

Assume that an existing recirculation loop operates at an average water temperature of 120ºF. The recirculation piping has a total length of 300 feet through an unconditioned crawl space where the air temperature is 55°F. The entire recirculation loop is piped with bare ¾" copper tubing. Figure 4-16 can be used to estimate the rate of heat loss from each foot of bare copper water tubing based on the difference in temperature

Figure 4-17



between the water in the tubing and the surrounding air.

300 feet of ¾" bare copper tubing
T_{water} = 120°F
T_{air} = 55°F
T difference = 65°F
Heat loss = 27 Btu/hr/ft * 300 feet
Total heat loss = 8,100 Btu/h

Assume that the HPWH is properly sized for the design load and has a heat pump only mode heating capacity (e.g., without electrical backup heating) of 8,500 Btu/hr. In this example, the heat pump essentially provides temperature maintenance for the recirculation loop, while the backup electrical element would be needed to help carry the hot water fixture load. This will lower the net COP of the HPWH system since a significant portion of the water heating was done by the electric-resistance elements rather than the heat pump refrigeration system.

The opportunity for energy savings is wasted when much of the HPWH's heat pump only mode output is required to offset heat loss in the recirculation loop. Reducing such losses when installing a HPWH increases cost but often yields a high return on investment.

See *idronics #21* for more information on balancingvalve applications for DHW recirculation.

Consider another retrofit example in which the recirculation loop ΔT is only 1°F. In this case, the domestic hot water recirculation pump is likely oversized. It is important to verify that the velocity of the recirculation piping isn't above 5 feet per second with copper pipe, when carrying water up to 140°F. In systems with higher temperatures, consult the piping manufacturer to determine the velocity limit. In some cases, the target velocity may drop to 2-3 feet per second. If the flow velocity within the recirculation piping is high, there is a greater likelihood of developing pinhole leaks as the piping material erodes.

Balancing valves are helpful to equally distribute water through all branches of the domestic hot water system. The recirculation pump will bring water around the piping circuit through the path of least resistance. This can create high velocity through certain risers or laterals, which can lead to pinhole leaks. In the service sector, this is often blamed on an undersized recirculation pump. Upsizing the recirculation pump often exacerbates underlying balancing issues and increases the likelihood of pin-holing the piping material, without reducing the wait times for hot water at the fixtures.

120 VAC HEAT PUMP WATER HEATERS

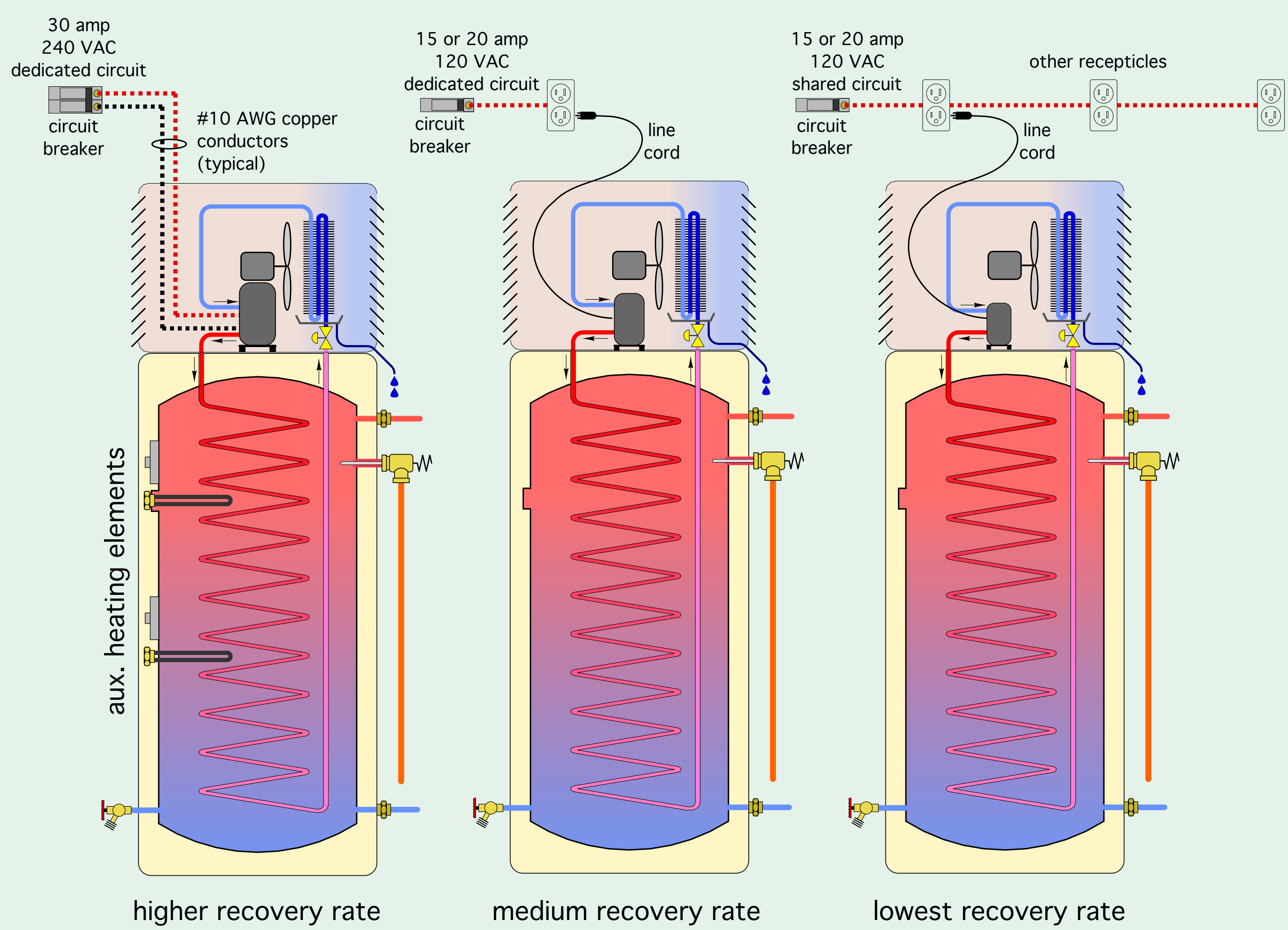
The earliest HPWHs installed in North America required 240V electrical input. In buildings constructed with natural gas, propane or fuel oil as the intended fuel for domestic water heating, a 240V dedicated circuit would have to be added to supply these units.

However, some existing gas-fired water heaters, as well as oil-fired water heaters, may already be

Figure 4-18

Courtesy of Hendricks Heating, Wyoming, MI

Figure 4-19



serviced by a dedicated 120V circuit. Recognizing this, some HPWH manufacturers have developed 120V models that could reuse this existing dedicated circuit. When possible, this reduces installation cost, especially in situations where a licensed electrician would have to be hired to install a new dedicated 240V circuit.

Some manufacturers also offer 120V HPWHs that can be plugged into a shared (rather than dedicated) 120V circuit. A retrofit example is shown in Figure 4-18.

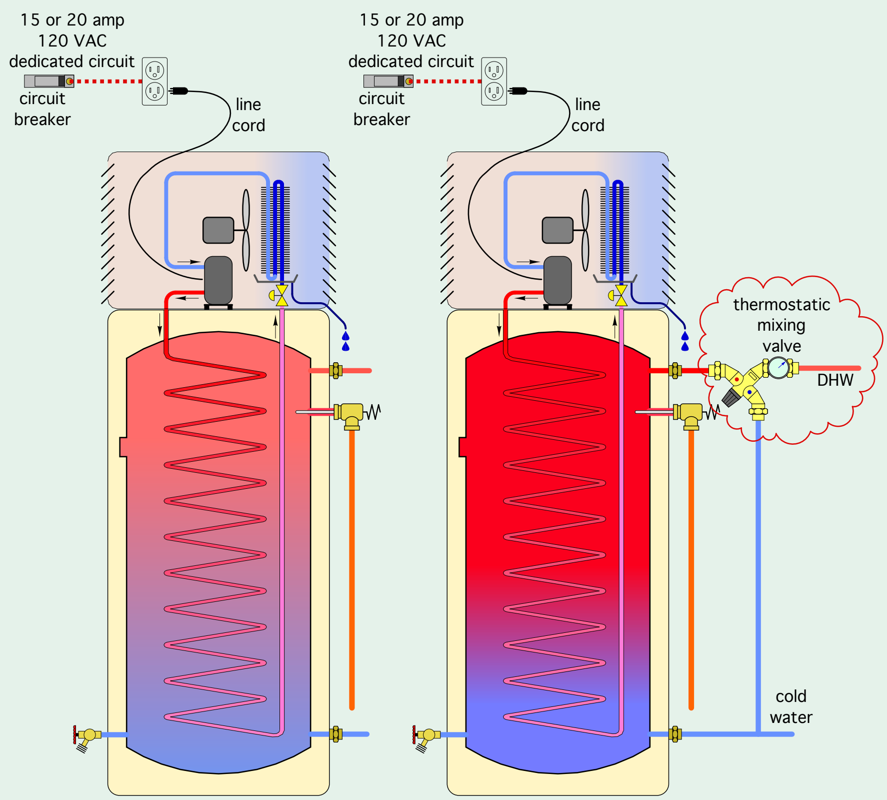
120V heat pump water heaters have lower recovery rates than 240V models. For example, one 50-gallon model designed for a dedicated 120V /15 amp circuit can provide 28 gallons per hour with a 60ºF temperature rise. A similar model with the same tank size, but intended to be used on a 120V /15 amp *shared* circuit can only provide 12 gallons per hour across the same temperature rise. This is due to a smaller compressor in the model designed for a shared circuit. Most HPWHs that are designed for 240V /30 amp dedicated circuits, and are equipped with auxiliary heating elements, can provide over 40 gallons per hour across the 60ºF temperature rise (see Figure 4-19).

The slower recovery rate associated with 120V HPWHs can be partially offset by operating them at higher storage temperatures in combination with an ASSE 1017 listed point-of-distribution mixing valve to reduce supply water temperature, as shown in Figure 4-20.

TANK SIZE

When replacing a gas-fired or electric-resistance water heater with a heat pump water heater, it's important to compare the first hour DHW production ratings. It may be necessary to increase the volume of a HPWH to reasonably match the recovery rate of the existing water heater — especially if it's a gas-fired unit. If a larger tank is selected to achieve the desired first hour

Figure 4-20



increasing storage temperature in combination with ASSE 1017 mixing valve to boost hot water delivery capacity

rating, be sure there is ample space available — especially height — to accommodate it. When a larger tank is not possible, consider operating the HPWH at a slightly higher storage temperature, combined with an ASSE 1017 rated thermostatic mixing valve to increase the amount of hot water available during high demand periods, as illustrated in Figure 4-19.

PLANNING FOR FUTURE REPLACEMENTS

The water heaters available for the replacement of a 15-year-old unit are likely different from the original installation. As policy, energy standards and production methods change, so does the available stock of potential replacement water heaters. This has always been the case, it is not a new phenomenon with HPWHs. It is likely that at the end of the service life of the equipment being installed today, a direct replacement might not be available. To simplify the eventual replacement of a water heater, always install isolation and service valves between the water heater and the remainder of the domestic water system.

5. ALTERNATIVES TO HEAT PUMP WATER HEATERS

Although dedicated heat pump water heaters are used for most domestic water heating applications and have been the primary focus of this issue, there are situations where other types of heat pumps, primarily intended for space heating or cooling, can be adapted to domestic water heating as an ancillary load. This section discusses some of the possibilities.

AIR-TO-WATER HEAT PUMPS USED FOR DOMESTIC WATER HEATING

One of the fastest growing segments of the global heat pump market is based on units that extract heat from outside air and transfer it to water or an antifreeze solution. Although these heat pumps are generally intended for space heating and cooling, they can also provide domestic water heating as an ancillary load. Using them in this manner helps provide a more complete HVAC offering in typical residential applications (e.g., space heating, cooling and domestic water heating.)

Figure 5-1 shows an example of a monobloc air-to-water heat pump connected to an indirect water heater tank. A heat exchanger within the tank separates a non-toxic antifreeze solution that passes through the heat pump from the potable water in the tank.

In a typical application, a motorized 3-way diverter valve directs the flow of hot fluid from the heat pump to either the heat exchanger within the indirect water heater tank, or to other parts of the system intended for space heating.

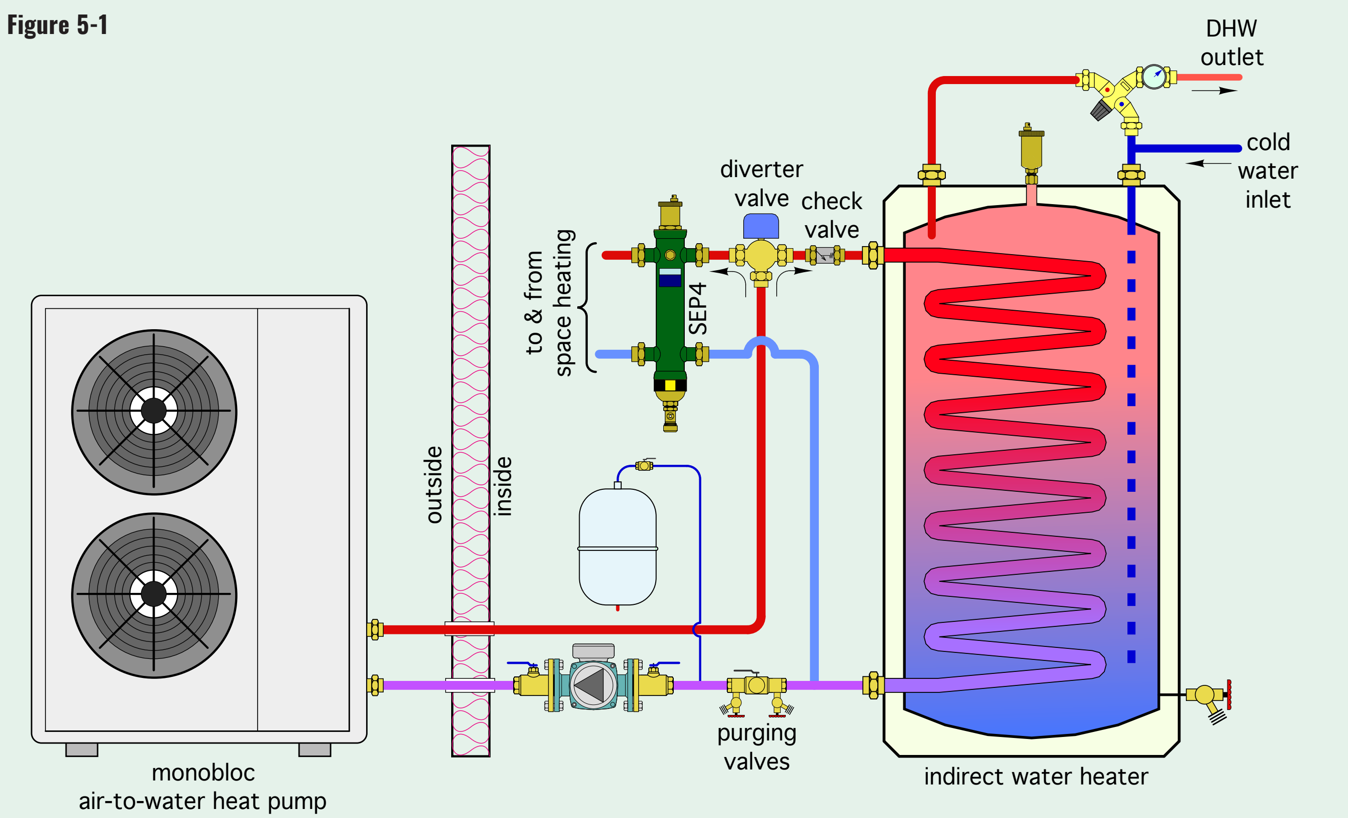
In this application, it is imperative to use an indirect water heater with a larger internal coil heat exchanger. The greater the surface area of this heat exchanger, the lower the fluid temperature exiting the heat pump can be, while still transferring the heat pump's full heat output to the water within the indirect water heater. Lower operating temperatures increase the heating capacity and COP of the heat pump.

If no suitable tank can be sourced, it is possible to use a properly sized external stainless steel heat exchanger in combination with a standard thermal storage tank.

When domestic hot water temperatures of 130ºF or more are required, the domestic hot water leaving the indirect tank can be routed through an auxiliary heater to boost its temperature as necessary.

Some air-to-water heat pumps have internal controls that monitor the temperature of the indirect water heater,

Figure 5-1



and automatically operate the diverter valve and the heat pump's refrigeration system whenever a call for domestic water heating is present. These controls can also be configured to allow the domestic water heating load to have temporary "priority" over space heating (or cooling) when there are simultaneous calls from both loads.

See *idronics #27* and *#30* for more information on air-to-water heat pump systems.

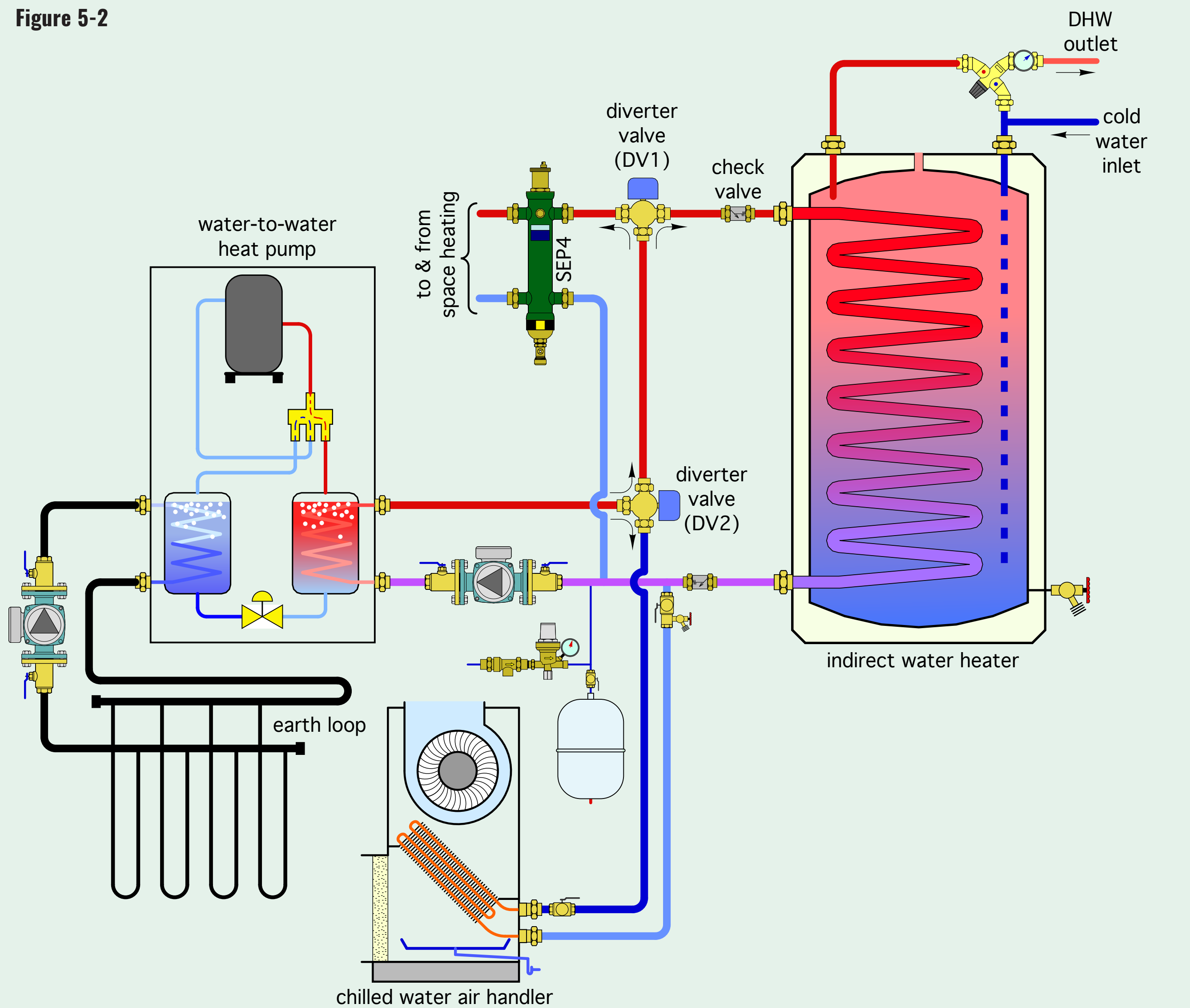
WATER-TO-WATER HEAT PUMPS USED FOR DOMESTIC WATER HEATING

Geothermal water-to-water heat pumps can also be configured to provide domestic water heating as an ancillary load. The piping can be similar to that used for an air-to-water heat pump, as shown in Figure 5-2.

Unlike the monobloc air-to-water heat pump system shown in Figure 5-1, antifreeze is typically not required between the water-to-water heat pump and the indoor portion of the system.

The system in Figure 5-2 has been expanded to include chilled water cooling using an air handler. A second diverter

Figure 5-2



valve (DV2) directs flow from the heat pump to either a heating load (e.g., space heating or domestic water heating) or to cooling. Diverter (DV1) directs heated water to either the indirect water heater or to space heating.

Some geothermal water-to-water heat pumps can also be equipped with "desuperheater" heat exchangers, which transfer heat from hot refrigerant leaving their compressor to a circulating stream of domestic water. Figure 5-3 shows the concept.

See *idronics #9* for more information on geothermal heat pump systems and *idronics #13* for more information on chilled water cooling.

HEAT RECOVERY APPLIED TO DOMESTIC WATER HEATING

Water-to-water heat pumps can also be applied in heat recovery applications. An ideal scenario is an industrial process where both chilled fluid and domestic hot water are needed at approximately the same time. One example would be producing a product such as gelatin. This process requires both ice and hot water. The energy used to produce the ice is reduced by any device or process that can cool incoming domestic water ahead of the icemaker. Likewise, the energy required for hot water is reduced by any device or process that can preheat the incoming cold domestic water. A water-to-water heat pump can do both of these processes simultaneously. The concept is shown in Figure 5-4.

The effective COP of the heat pump in this type of application can be very high. The reason is that both the chilled water and preheated domestic water are *useful*

Figure 5-3

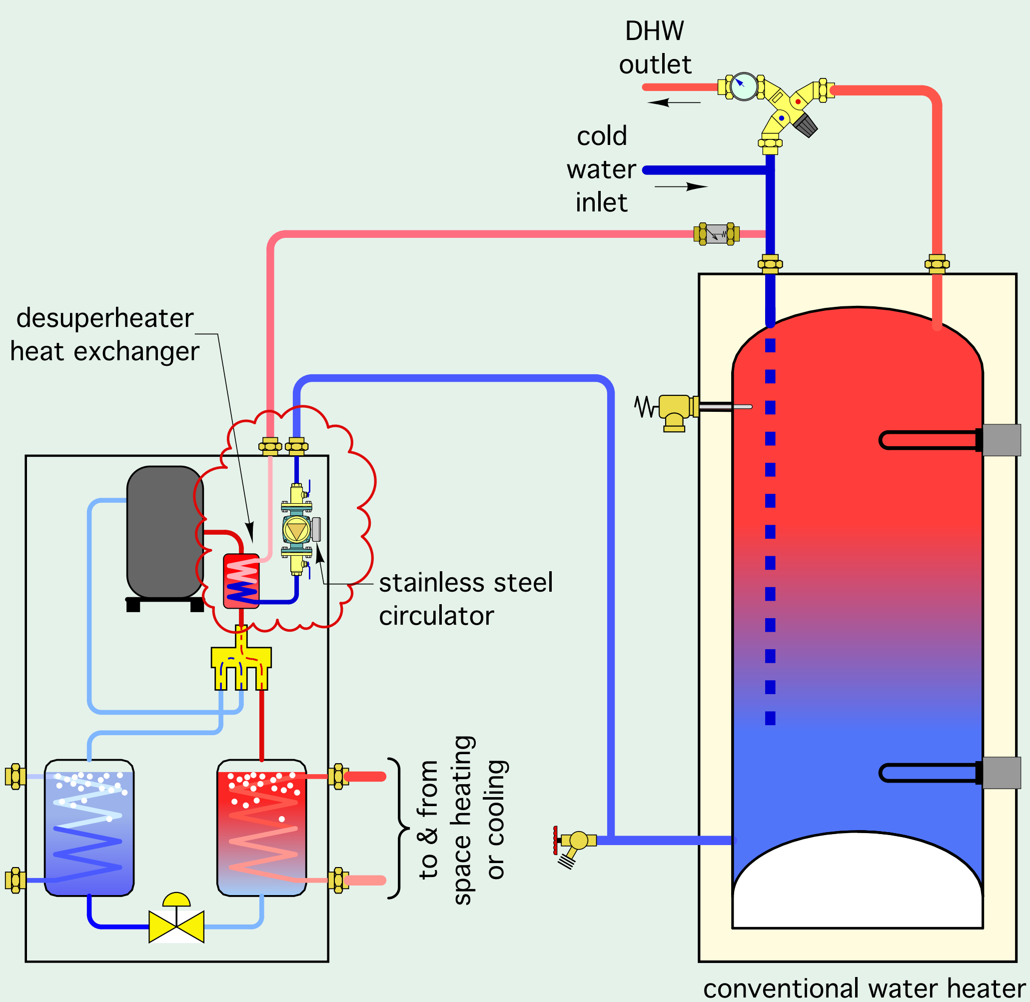
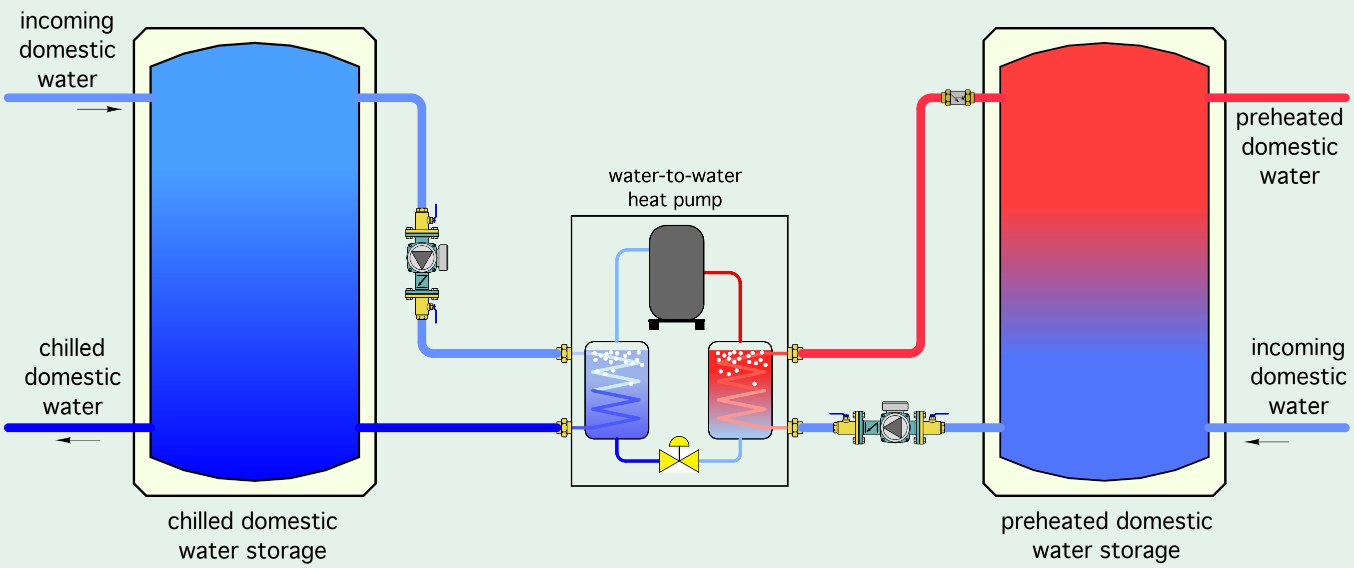


Figure 5-4



outputs that displace what would otherwise be additional energy input to produce the same output streams using separate heating and cooling devices. In theory, the effective COP of the water-to-water heat pump in these applications would be:

Formula 5-1:

$$COP_e = (2 \times COP_{HP} - 1)$$

Where:
COP_e = effective COP of the heat pump system in this application
COP_{HP} = COP of the heat pump at the operating conditions imposed by the two entering water streams

For example, a heat pump operating with a COP of 3.0 in a heat-recovery application where both output streams are useful would be:

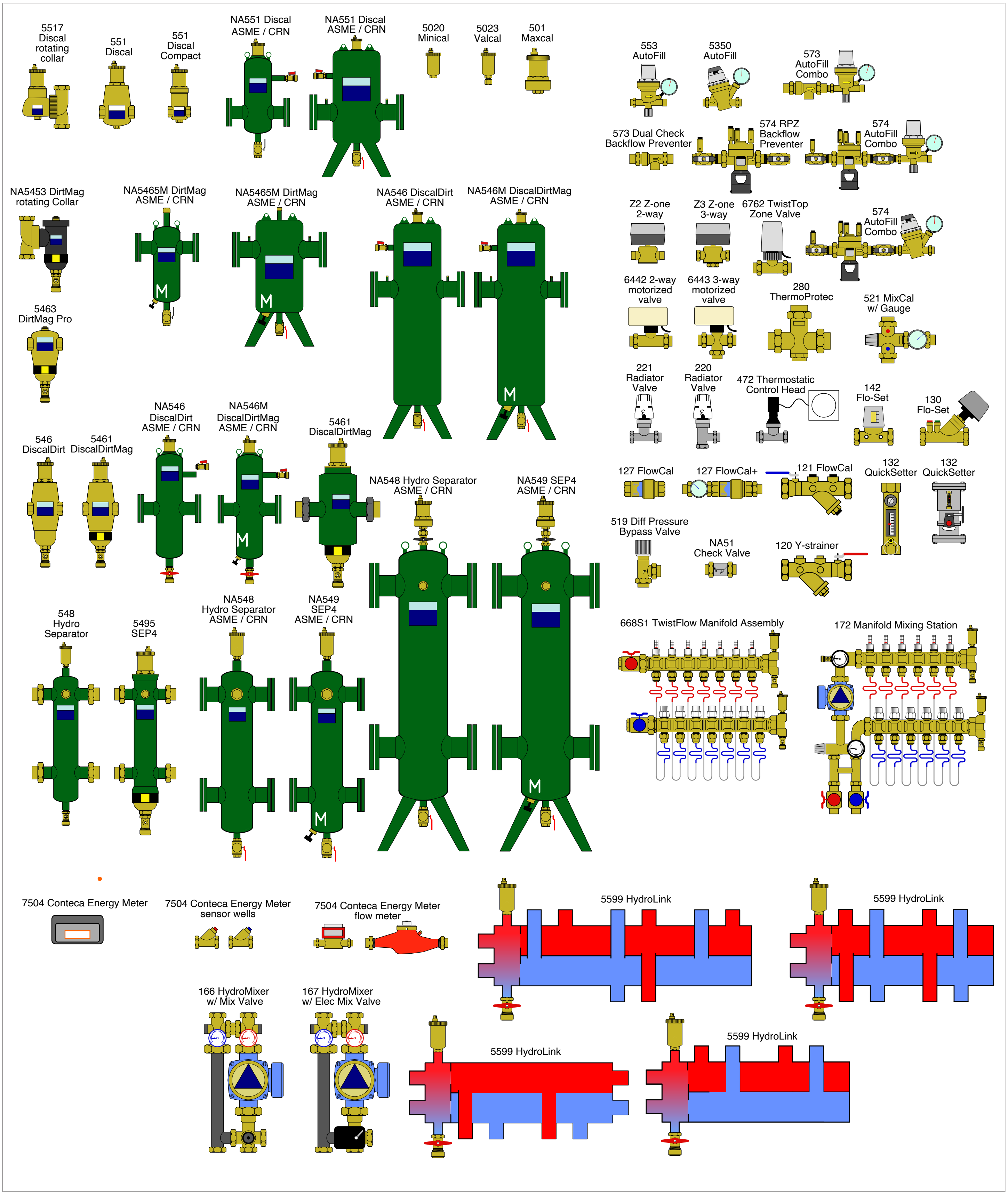
$$COP_e = (2 \times COP_{HP} - 1) = (2 \times 3 - 1) = 5$$

6. SUMMARY

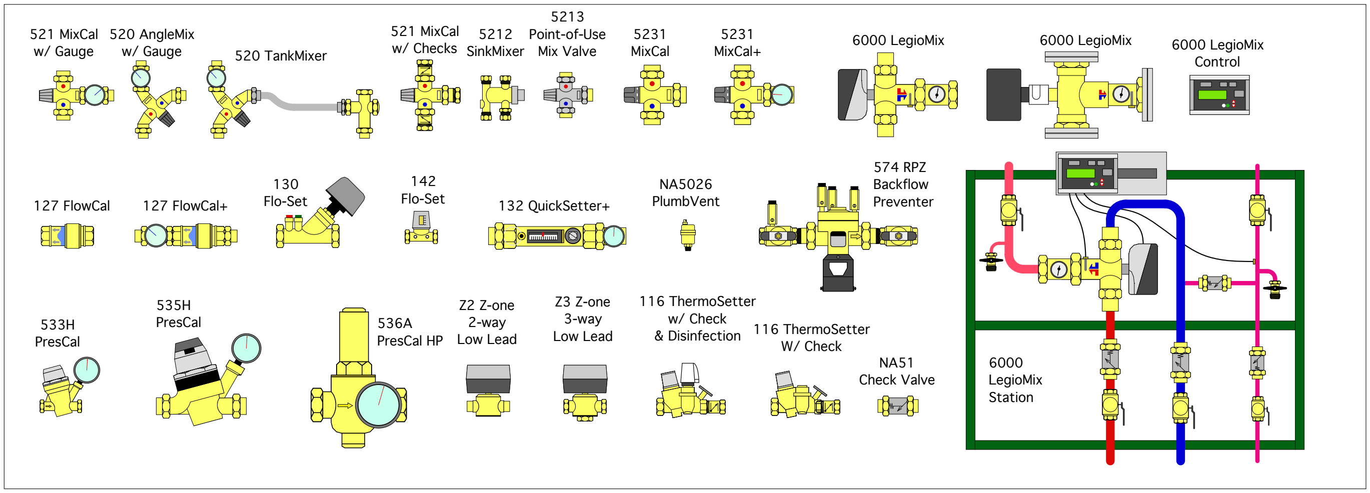
Properly designed and installed HPWH systems can significantly reduce the energy required for heating domestic water while delivering hot water with short wait times to building occupants.

As is the case with any mechanical equipment, proper application and installation leads to optimal results. HPWHs selected and installed in ways that maximize their COP have the potential to reshape the domestic water heating market while increasing the use of renewably generated electricity. They help building owners by lowering utility bills, while also benefiting utilities with decarbonization and load management strategies.

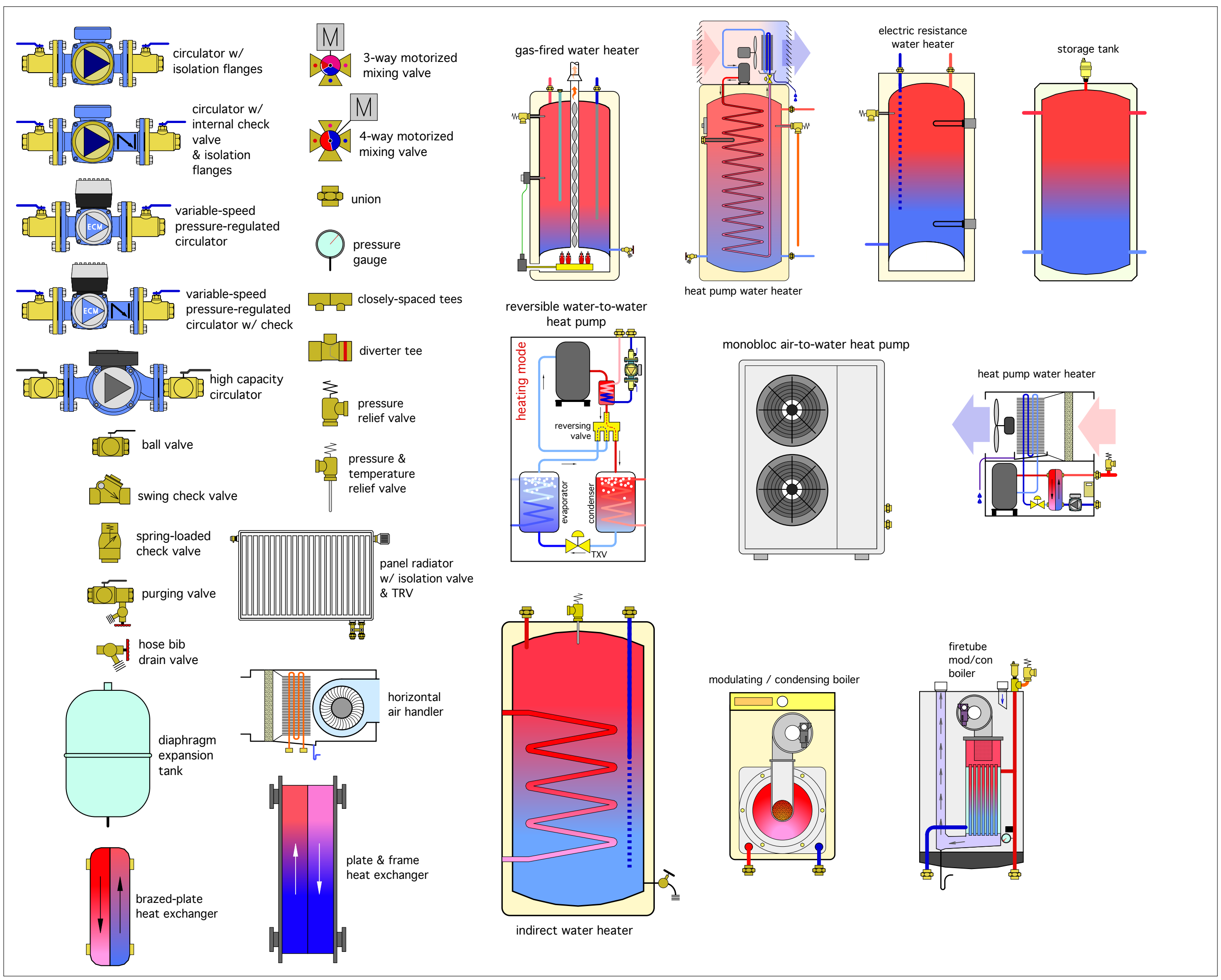
APPENDIX A: CALEFFI HYDRONIC COMPONENTS



APPENDIX B: CALEFFI PLUMBING COMPONENTS



APPENDIX C: GENERIC COMPONENTS



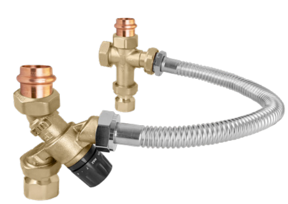
520 SERIES TANKMIXER™ THERMOSTATIC MIXING VALVE

THE PERFECT MIX

The Caleffi TankMixer™ is a perfect mixing valve solution to maximize the capacity of modern high efficiency water heaters and minimize installation time. It comes packaged in a kit with everything needed for fast installation including the award-winning AngleMix™ thermostatic mixing valve and cross fitting with check valve and a recirculation connection.

MAX WORKING PRESSURE	150 psi (10 bar)
SETTING TEMP RANGE	95°- 150°F (35°- 65°C)
MAX HOT WATER INLET TEMP	195°F (90°C)
MIN FLOW FOR STABLE PERFORMANCE	0.5 GPM (2 l/min)

PRODUCT RANGE - TankMixer™ 520 Series



ICC ES PMG LOW LEAD

NSF/ANSI 372

CONNECTION TO TANK	CONNECTION TO SYSTEM	CODE	
		WITHOUT MIXED OUTLET TEMPERATURE GAUGE	WITH MIXED OUTLET TEMPERATURE GAUGE
¾" FNPT	¾" MNPT	**520**500AX	**520**510AX
	¾" PRESS	**520**506AX	**520**516AX
	¾" SWEAT	**520**509AX	**520**519AX

*Kit includes AngleMix mixing valve, cold water cross with check valve, 18” large ID flexible pipe and recirculation port plug (½”).

PRODUCT FEATURES

COMPLETE QUICK-CONNECT KIT:

Everything needed for quick installation, including fittings and cold water cross fitting with check valve to prevent a cross connection.

ACCURATE LOW FLOW:

0.5 GPM minimum flow for stable control for today's high efficiency fixtures.

TIGHT HOT WATER CLOSE-OFF:

Prevents recirculation temperature creep. Improves pump's aquastat service life.

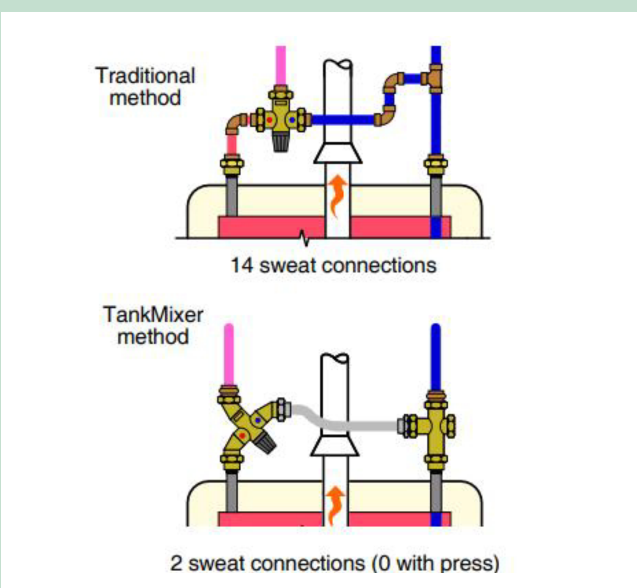
OPTIONAL TEMPERATURE GAUGE:

0.5 GPM minimum flow for stable control for today's high efficiency fixtures.

INTEGRAL RECIRCULATION PORT:

½" FNPT connection on the cross for recirculation (if used)

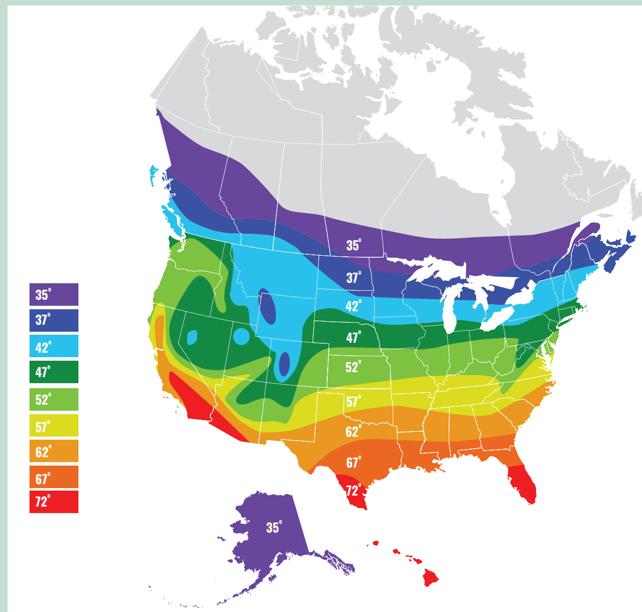
APPLICATION DIAGRAM



ANTI-SCALE POLYMER MATERIALS:

Prevents scaling on internal sliding surfaces, assuring stable temperature control and long life.

GETTING MORE HOT WATER



Determine your ground water temperature from this map. This is the supply water temperature to your water heater.

Then, using the table below, determine the potential increased capacity of hot water by incorporating a TankMixer™ on your water heater.

For example, in Atlanta, GA, setting the water heater to 160°F, increases capacity by 69%. This equates to 84 gallons for a 50 gallon heater.

The TankMixer works great to extend the capacity of your existing or new water heater.

% Increase in Water Heater Capacity*									
Storage Temp	Incoming Water Temperature (°F)								
	35°	37°	42°	47°	52°	57°	62°	67°	72°
130°F	12	12	13	14	15	16	17	19	21
140°F	24	24	26	27	29	32	34	38	42
150°F	35	36	38	41	44	48	52	57	63
160°F	47	48	51	55	59	63	69	75	83
170°F	59	60	64	68	74	79	86	94	104
180°F	71	72	77	82	88	95	103	113	125

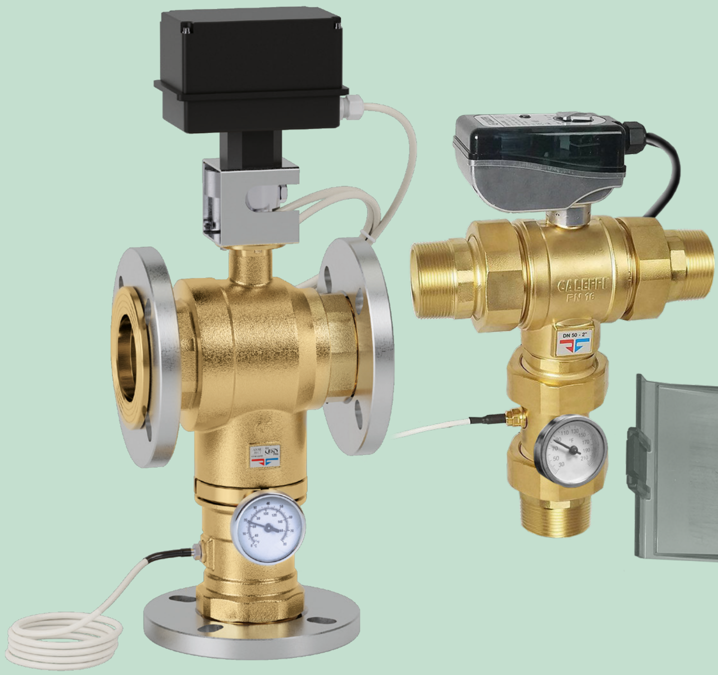
*baseline 120°F

ICC ES PMG LOW LEAD

6000 SERIES LEGIOMIX® ELECTRONIC MIXING VALVE

ADVANCED MIXING CONTROL

LEGIOMIX® is an advanced electronic mixing valve with digital control of temperature for commercial domestic hot water systems. The daily exercise function keeps the ball valve free of scale build-up to ensure smooth operation. Rated highest in the market for flow capacity, this twice recognized AHR Innovation Awards product also has an industry exclusive, calendar-based scheduling program for automatic circuit thermal disinfection.



PERFORMANCE

MAX. OPERATING PRESSURE	150 psi (10 bar)
SETTING TEMPERATURE RANGE	70 — 185°F (20-85°C)

PRODUCT RANGE - LEGIOMIX® 6000 Series

SIZE	Cv	MIN. FLOW (GPM) *	DESIGN FLOW (GPM) **	MAX. FLOW (GPM) ***	CODE		
					NPT	SWEAT	PRESS
¾"	9.7	2.2	27	43	**6000**54A	**6000**59A	**6000**56A
1"	9.7	2.2	27	43	**6000**64A 001	**6000**69A 001	**6000**66A 001
1"	21	3.1	58	94	**6000**64A	**6000**69A	**6000**66A
1¼"	24	4.4	66	107	**6000**74A	**6000**79A	**6000**76A
1½"	34	6.6	93	152	**6000**84A	**6000**89A	**6000**86A
2"	47	8.8	131	215	**6000**94A	**6000**99A	**6000**96A
2½"	105	17	288	470	**6000**60A flanged	--	--
3"	120	22	329	537	**6000**80A flanged	--	--

*To ensure stable operation and accurate temperature control. Minimum flow is 0 gpm when recirculation flow rate is ≥ the valve's minimum flow rating.
**Suggested maximum flow rate for optimum modulating control (at 7.5 psid pressure drop).
***Maximum recommended differential pressure is 20 psid for smooth and quiet operation.
Inlet port check valves are available for field installation, code NA10366 (1", 1¼") and NA10367 (1½", 2").

ICC ES PMG LOW LEAD

Meets requirements of NSF/ANSI 372-2011 and complies with ASSE 1017, CSA B125.3, UPC, IPC, Low Lead Laws and listed by ICC-ES for use in accordance with the U.S. and Canadian plumbing codes. Meets requirements of CSA Z317.1 Special Requirements For Plumbing Installations In Health Care Facilities.

PRODUCT FEATURES

MARKET'S HIGHEST RATED FLOW CAPACITY:

DZR low-lead brass body, full-port ball valve, ¾" to 3" connections, 2.2 to 537 gpm flow rates.

SELF CLEANING:

Automatic daily ball rotation to scrape away any scale or debris, ensuring smooth operation.

FULL FUNCTIONALITY WITHOUT A LAPTOP:

All configuration, set points, temperatures, run status, alarms and datalogging functions are available at the user interface without the need for a laptop.

THERMAL DISINFECTION PROGRAMS:

Calender based programs for scheduling thermal disinfection to control Legionella in recirculation circuit.

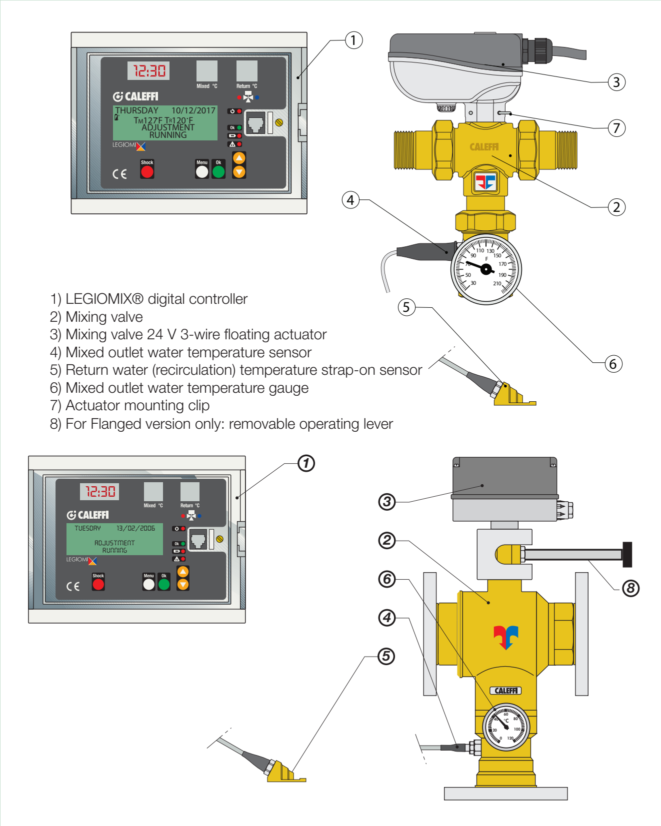
UNION PIPE FITTINGS:

¾" through 2" models have all-union connections for easy maintenance and service without piping modifications.

BAS-READY:

Integral MODBUS® is standard. Optional MODBUS-BACnet™ gateway for remote access to building automation system.

COMPLETE PACKAGE



APPLICATION DIAGRAM