Air-to-Water Heat Pump
Design and Installation Guide

How to tap this exciting new technology to convert existing homes to all-electric heating, cooling, and water heating

Prepared by Frontier Energy Inc. for Sonoma Clean Power

California Energy Commission Grant No. EPC-17-041

October 2021

Acknowledgements

The authors would like to acknowledge the efforts of the following partners and individuals who helped make this guide possible:

Sonoma Clean Power

California Energy Commission

Mike MacFarland (Energy Docs)

John Siegenthaller

Joe Bonney (Heatwave Systems)

John Grose (Hydronic Specialties Company)

Rick Chitwood

The customers of Sonoma Clean Power who volunteered their homes for experiments to validate the information presented in this document.

Contents

Glossary

ACCA	Air Conditioning Contractors of America Association, Inc
AHRI	Air Conditioning, Heating, & Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
AWHP	Air-to-water heat pump
Btuh	British Thermal Units per Hour
CFM	Cubic Feet per Minute
COP	Coefficient of Performance
DB	Dry Bulb
DOE	Department of Energy
EER	Energy Efficiency Ratio
ERV	Energy Recovery Ventilator
EWT	Entering Water Temperature
GPM	Gallons Per Minute
HRV	Heat Recovery Ventilator
HVAC	Heating, Ventilation and Air Conditioning
IPLV	Integrated Part Load Value
MBH	Thousand British Thermal Units per hour
MERV	Minimum Efficiency Reporting Value
Psi	Pounds per Square Inch
SEER	Seasonal Energy Efficiency Ratio
SHR	Sensible Heat Ratio
UEF	Uniform Energy Factor
VC-AWHP	Variable capacity air-to-water heat pump
VOC	Volatile Organic Compound
w.c.	Water Column
WB	Wet Bulb

I. Introduction

What is an Air-to-Water Heat Pump?

Just like conventional “split system” heat pumps air-to-water heat pumps (AWHPs) consist of an outdoor unit that contains a compressor, finned coil, and fan, and piping that connects to an indoor distribution system. What is different is that they use water to convey heat to or from air handlers or other distribution components instead of refrigerant. The heat exchange to indoor components is from water to air instead of refrigerant to air. Figure 1 shows the basic components of the outdoor unit.

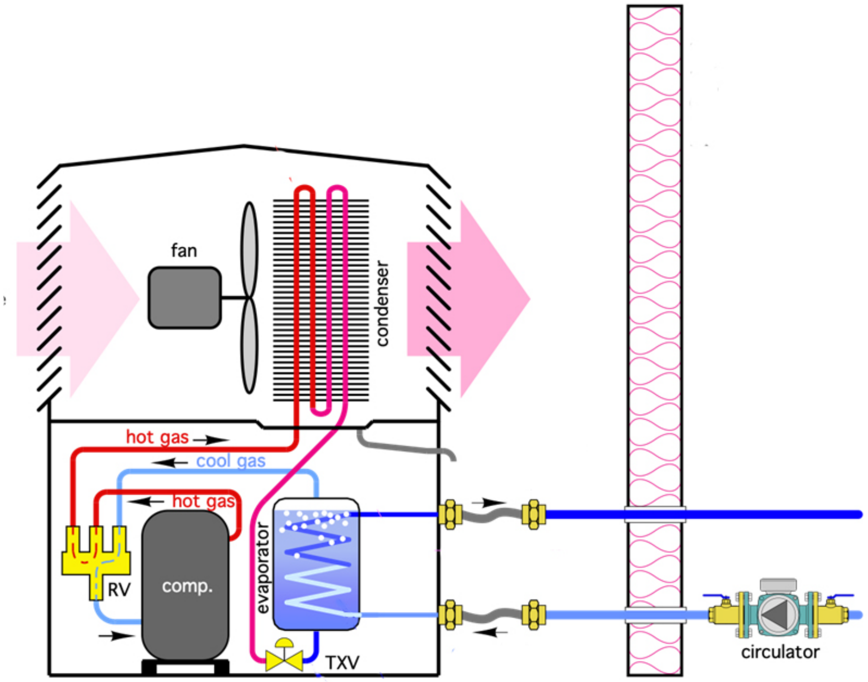


Figure 1. Simplified diagram of the inner workings of an AWHP.
Image credit: John Siegenthaller

Who Can Benefit from This Guide?

This Guide is designed to help homeowners who want to make their homes more energy efficient and less reliant on natural gas, energy consultants who need information on compliance methods, designers who can benefit from increased knowledge and resources, and mechanical contractors interested in expanding services. More specifically, this Guide will:

1. Educate homeowners, designers, and installers on applications and benefits of air-to-water heat pumps (AWHPs) relative to gas heating systems and air-to-air heat pumps
2. Recommend best practices that reduce the amount of time designers need to design systems and installers need to install them
3. Ensure that systems deliver the efficiency, comfort, and reliability they are capable of

The focus is on design and installation of AWHP in existing homes, but the information provided can also be applied to new construction. Given the lack of familiarity that most HVAC contractors have with hydronic systems in California, general information on the design and installation of hydronic systems is covered and a design example is provided.

Advantages of Air-to-Water Heat Pumps

AWHP's have been available in California for over ten years but are still not common. Here are some reasons why homeowners, designers, and contractors should become familiar with them:

- They can be used with forced air distribution, radiant panels, or both.
- They can provide heating, cooling, and water heating from one outdoor unit, often called "triple" or "three function" operation.
- They allow for zoned distribution without the problems associated with furnaces and air-to-air heat pump systems.
- "Monoblock" (or "monobloc") systems are factory charged so there is no risk of leakage from connections and field discharge of refrigerants.
- In most cases they can be installed without electric resistance heat for space heating or water heating, reducing energy use and peak electricity.

Meeting California's 2045 zero carbon emissions goal[1] will require every existing home to replace gas furnaces and water heaters with heat pump-based systems. Many homes built before the 1980s have 100 or 125 amp electrical services which cannot support the installation of air-to-air heat pumps and heat pump water heaters, let alone electric cooking appliances. The cost to upgrade an electrical service to 200 amps varies depending on whether the existing service is above or below ground. Above ground panel upgrades may cost as little as $2,000. For underground service, the cost will depend on whether the cable is in a conduit or directly buried and may exceed $7,000. Several sources cite an average cost of $4,256.[2]

AWHPs offer the following advantages for electrifying older homes:

- In many cases they may eliminate the high cost of upgrading the electrical service because they use a single compressor for space conditioning and water heating
- With proper sizing they can be installed without inefficient electric resistance heating that is needed by air-to-air heat pumps for defrost cycle reheat and by heat pump water heaters for supplemental heat
- They do not require adding a 240V circuit for the air handler as may be required for air-to-air heat pumps

II. Introduction to AWHP Systems

Types and Features

Monoblock vs. Split Systems

In monoblock systems the refrigerant-to-water heat exchanger is incorporated into the outdoor compressor unit and hot or chilled water is delivered to the indoor air handler, fan coils, or other terminal distribution units. In split systems the heat exchanger is separate from the outdoor unit and connected by refrigerant lines. Both system types, shown in Figure 2, are used in hydronic systems and

---

[1] https://www.energy.ca.gov/sb100

[2] For example, Energy and Environmental Economics 2019 report, Residential Building Electrification in California

deliver space heating and cooling using air handlers, fan coils[3], and/or radiant panels. Monoblock systems are most common and may include a pump as well as components normally required in hydronic systems, which simplifies and speeds installation.

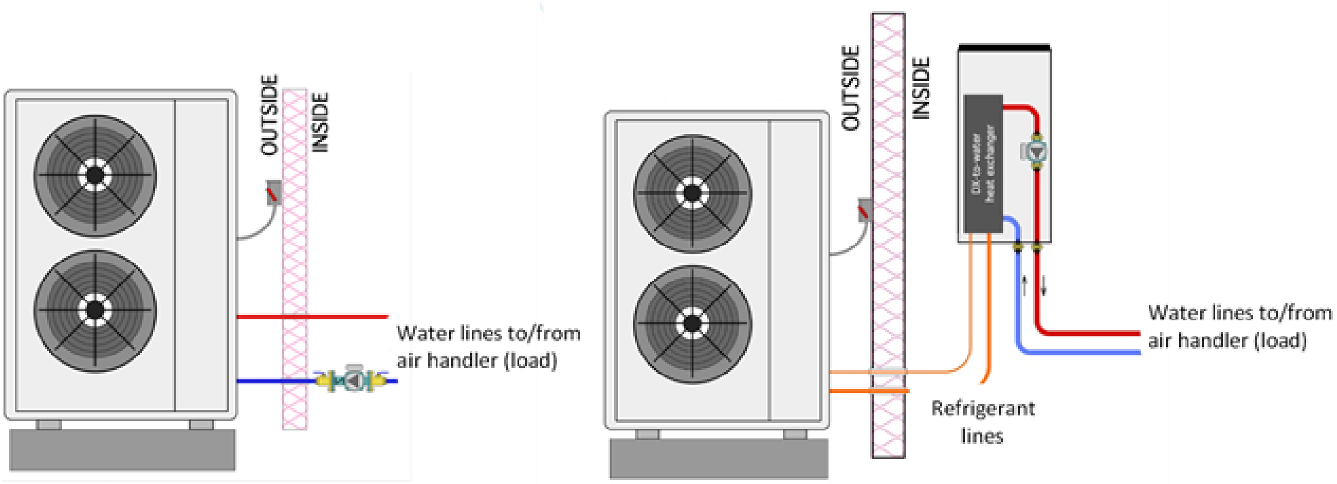


Figure 2: Monoblock vs. Split System Air-to-Water Heat Pumps
Image credit John Siegenthaller

Heating and Cooling Capacities

The California Energy Commission's Modern Appliance Efficiency Database System (MAEDBS) currently lists residential scale AWHP equipment having cooling capacities from 26 to 49 MBH and heating capacities from 28 to 66 MBH (at 95°F and 47°F outdoor temperatures respectively). The MAEDBS also lists commercial scale systems with capacities over 1,400 MBH which can serve large multifamily buildings.

Compressor & Fan Speed Control

The means of controlling compressor and fan speed is another distinguishing feature. Currently, AWHPs are available as single speed, dual speed, or variable speed compressor systems with either single speed or variable speed fans. From the perspectives of efficiency and design flexibility, systems using variable speed compressors and fans are preferable, as they can modulate capacity to meet load. These Variable Capacity AWHPS (VC-AWHPs) are less likely to require a buffer tank, simplifying installation and saving labor and materials cost.

---

[3] For purposes of this document air handlers are defined as central units that include a fan and refrigerant or hydronic coil that distribute air through ducts. Fan coils tend to be smaller, serve individual spaces, and are either not ducted or use short ducts.

Certifications and Performance Rating Methods

The California Energy Commission requires that AWHP products installed in California be listed in the MAEDBS[4]. To be listed, manufacturers must have equipment tested under AHRI 550-590[5]. Information that must be submitted to the Commission and that is listed in the MAEDBS includes but is not limited to:

- Refrigerant type
- Compressor motor design (Single-speed, Dual Speed, Variable Speed)
- Outdoor unit fan motor design (Single-speed, Dual Speed, Variable Speed)
- Heating capacity at 47°F and 17°F
- Heating COP at 47°F and 17°F
- Cooling capacity at 95°F
- Cooling EER
- Integrated part load value (IPLV)

AHRI 550-590 tests are completed at supply water temperatures of 120°F for heating and 44°F for cooling. Since this test standard is not the same as the standard used for air-to-air heat pumps (AHRI 210/240) it is not possible to directly compare AWHP and air-to-air heat pump performance ratings.

For air conditioners and air-to-air heat pumps seasonal cooling efficiency is represented by the SEER rating. The closest equivalent to that for AWHPs is IPLV. IPLV is calculated using a weighted average of EERs measured at four entering outdoor air temperatures. Systems with variable speed compressors and condenser fans tend to have higher IPLVs.

Another difference between AWHP and air-to-air system ratings is that air-to-air systems are rated for specific indoor refrigerant coils at indoor dry bulb and wet bulb temperatures, whereas AWHPs are rated based on delivered water temperature and their performance will vary with the hydronic coil they are paired with.

It is possible to develop a domestic water heating efficiency rating for AWHPs using the same tests and uniform energy factor (UEF) rating methods as used for heat pump water heaters[6], but there is no rated water heating performance data available for AWHP products at this time. Unlike heat pump water heaters, due to their higher capacity AWHPs do not generally require electric resistance heat backup which improves efficiency.

III. Design Considerations and Project Planning

Planning for an Efficient and Healthy Home

Before embarking on any project to install a new heating and cooling system, attention should be given to the building envelope (including ducts) and indoor air quality. Both are essential to ensuring efficient operation, occupant comfort, and customer satisfaction. Advantages to improving the building envelope

---

[4] https://cacertappliances.energy.ca.gov/Pages/Search/AdvancedSearch.aspx. *Category* is “Central Heat Pumps” and *Appliance* is “Heat Pump Water Heating Packages.” Filter by “Phase Equals 1” for a list of residential units.

[5] California Code of Regulations Title 20, Section 1604(c). See also California Energy Commission Docket 15-AAER-01, TN#204337.

[6] Code of Federal Regulations Title 10, Part 430, Appendix E to Subpart B – Uniform Test Method for Measuring the Energy Consumption of Water Heaters

and distribution system include the potential to downsizing the HVAC system, eliminate drafts and cold spots.

Best Ways to Improve Efficiency

Rather than investing in sealing old, leaky, poorly insulated, poorly designed, and poorly installed ducts, a better strategy is to remove the ducts, vacuum out old attic insulation, and seal leaks in the ceiling. Then new properly sized ducts insulated to R-6 can be installed with shortened runs and deeply buried in new attic insulation. This provides better protection against summer heat gain and winter losses and guarantees against callbacks and failed HERS tests. California Title 24 Standards will likely force addressing these issues anyway. When heating and cooling equipment is replaced, California's Title 24 standards require that duct leakage be tested and that ducts be sealed to limit air leakage to 10 percent of system airflow. If the proposed project includes adding more than 25 feet of duct, Title 24 standards will require that all ducts be replaced.[7]

Since every home and living situation is unique, there isn't a single device or item that will universally improve a home's efficiency. But with the introduction of modern building performance test equipment in the late 90's and early 2000's, it is now possible for skilled technicians to test the installed performance of all energy features in a home. What this means for homeowners is they no longer need to guess at what specialty trade (HVAC, insulation, window salesperson) to call to identify and solve their efficiency needs.

A home performance expert will come armed with a calibrated blower door, infrared camera, tape measure, window glazing detector, power meter and airflow hood (and many other tools) to measure and evaluate the performance of a home's air boundary, insulation performance, ventilation and heating and cooling system efficiency. Using energy modeling and HVAC design tools along with an understanding of how you use your home, the expert can identify the most effective ways to improve your efficiency, indoor air quality and comfort, creating a report and plan for upgrading the efficiency of your home.

Learning more about the process and locating a home performance expert in your area should start with a visit to the Department of Energy website.[8] There you will find a zip code search for Home Improvement Experts in your area and checklists by topic for common home energy efficiency projects. Best results will be obtained when you inquire about their testing processes and choose only the expert who won't make recommendations without first testing and inspecting your home energy features.

Additional information about the measured home performance process, as well as additional energy efficiency retrofit measures and best practices, can also be found in the book "Measured Home Performance" by Rick Chitwood and Lew Harriman.[9]

Maintaining a Healthy Indoor Environment

There is a mantra in the building science community: "Build tight ventilate right." Reducing leakage through non-weather-stripped windows and doors, attic leaks, and leaky ducts saves energy but also reduces the dilution of indoor contaminants including volatile organic compounds (VOCs), particulates,

---

[7] This will be reduced to 10 feet in 2023.

[8] https://basc.pnnl.gov/home-improvement-expert

[9] https://www.gti.energy/wp-content/uploads/2018/10/Best-Practices-Guide-v2Complete-lo-res-11-30-2012.pdf (Archive)

virus particles, and excess moisture. New homes in California and elsewhere are required to provide mechanical ventilation. Using continuously operating exhaust fans or installing heat or energy recovery ventilators (HRVs & ERVs) that provide balanced ventilation are common methods of providing ventilation.

The methods utilized in ASHRAE Standard 62.2[10] and the Title 24, Part 6 standards[11] for calculating the minimum mechanical ventilation rate for new homes are complicated. The following equations should be used to determine the ventilation rate for well-sealed existing homes. They use simplifying assumptions (including a leakage rate of 5 ACH50) and are within ±6 percent of the detailed calculations for homes from 1200 to 4000 ft^2. Balanced systems supply and exhaust about the same volume of air resulting in approximately equivalent indoor-outdoor pressures whereas exhaust fans create negative indoor pressures.

For balanced ventilation systems (e.g., HRV & ERV): Fan CFM = Floor Area x 0.019 + 23
For unbalanced systems (e.g., bath exhaust fans): Fan CFM = Floor Area x 0.028 + 26

There are two other important things to remember for maintaining a healthy home:

- Use filters with a MERV rating of 13 or higher (equivalent to an FPR rating of 10 and an MPR rating of 1500-1900) on both air handlers and HRVs/ERVs. The size of return air grilles may have to be increased to keep friction loss below 25 Pascals (0.10 inches water column) due to the higher friction loss of higher efficiency filters.
- Ensure that the kitchen hood has an airflow rating of at least 100 cfm and is connected to a duct that exhausts air to outdoors. Recirculating hoods do not remove pollutants. Recent research has shown that range hood airflow should be over 200 cfm to effectively capture hazardous particles and VOCs. Homeowners should be instructed on the importance of turning on their range hoods prior to turning on burners or any other cooking appliance. Those that operate more quietly are more likely to be used.

AWHP System Options for Existing Homes

There are three options for integrating AWHPs into existing heating and cooling systems:

1. Replace the central system furnace with an air handler that includes a fan and water coil and connect it to existing ducting.
2. Remove the central system furnace and install fan coils (small air handlers) to serve smaller areas such as individual rooms. These can either be wall or ceiling-mounted or enclosed in closets and can be ducted short distances to serve more than one room.
3. Install radiant ceiling panels in each room or use them to supplement heating and cooling delivery for hard-to-reach rooms.

If an existing furnace is being replaced and the ducts are in good condition, then Option 1 will be the least cost and simplest to execute. If ducts are in poor condition and difficult to replace, then Option 2 might be preferred because the existing duct system can be abandoned. This option also eliminates all or most of the distribution losses associated with attic ducts.

---

[10] https://www.techstreet.com/ashrae/standards/ashrae-62-2-2019?product_id=2087691
[11] https://www.energy.ca.gov/sites/default/files/2021-06/CEC-400-2018-020-CMF_0.pdf (Archive)

Option 3 also eliminates duct loss and is invisible when properly installed, but installation can be disruptive because ceilings must be covered to about 50 to 80 percent with radiant panels. Spacers and drywall are installed where there are no radiant panels to maintain a flat ceiling surface. This work requires removal and remounting or replacement of all ceiling fixtures, with some minor relocation to avoid direct tubing contact. Radiant heating and cooling is quiet, comfortable, and efficient but it is only recommended for gut rehabs or additions, or as an alternative to fan coils in individual rooms that are hard to reach with ducting.

For larger additions with concrete floors, it is relatively inexpensive to embed tubing in the concrete. Radiant floors provide enhanced comfort in the heating season and can be used for off-peak thermal storage in the cooling season. This strategy should not be used with floors that are extensively carpeted or have wood or vinyl floor coverings due to the risk of condensation and moisture accumulation.

Using the Heat Pump for Domestic Water Heating

If it is desired to use the AWHP to heat water for domestic use, then that should also be considered in the planning stage. This approach is desirable if the intention is to fully electrify the home and it does not currently have a 200-amp service. Using the AWHP instead of a separate heat pump water heater might avoid the need to upgrade the electrical service. Since AWHPs have higher heating capacity than heat pump water heaters and do not require supplemental electric resistance heating, they are also more efficient. However, due to the way many AWHPs are controlled, the water temperature is usually limited to about 125°F.

A 125-amp service might provide sufficient capacity to serve an all-electric home up to 2500 ft^2 or more if the AWHP is used for domestic water heating as well as space heating and cooling. This depends on what appliances are in the home and their electrical ratings, but a 125 amp service might accommodate an electric stovetop and oven, microwave oven, garbage disposal, and clothes dryer. A 200 amp service would likely be needed if an electric vehicle charging circuit is added, though a smart circuit splitter could be installed to share the clothes dryer circuit.

Planning for AWHP System Components

Where to Place the AWHP Outdoor Unit

Figure 3. Left: Old outdoor unit. Right: New outdoor unit, installed in approximately the same location as old unit (moved back a bit for clearances).

If an air conditioner is being replaced, the existing electrical wiring and disconnect can be used for the AWHP and in most cases the existing 240V service can be used. The existing breaker may need to be replaced with a lower capacity breaker, even though the existing wiring is likely oversized relative to the requirements of the new equipment, to provide adequate protection.

AWHPs are usually taller and narrower than air conditioner condensing units and have a smaller footprint. Piping to indoor distribution equipment can follow the same route as the air conditioner refrigerant piping. If an air conditioner was not previously installed, then the location of the AWHP will depend on how easily it can be connected to power and to the indoor distribution equipment, available space, and aesthetic considerations. Additionally, and specific to heat pump technology, there are water runoff considerations including but not limited to roof and outdoor coil condensation and defrosting that should be considered when planning walkways.

Indoor Air Handler

Figure 4. Left: Old equipment which included a gas water heater and furnace. Right: Replacement equipment which includes an indirect DHW tank, hydronic air handler, and buffer tank.

A hydronic air handler can usually be installed at the same location as the gas furnace it replaces and can use the same duct connections. Space is not a concern for furnaces mounted in garages and attics, but if a furnace is installed in an indoor closet the allowable space for an air handler must be verified during the design process. Be sure to ensure that the air handler and coil are designed to provide both heating and cooling and include a condensate drain. Multi-row flat coils are very common in hydronic forced air heating systems but lack condensate drains.

Buffer Tank

Buffer tanks are used either in series with distribution system components (fan coil units or radiant panels) connected to either the supply or return piping to add volume to the system or they can be connected to both supply and return piping between the AWHP and the distribution system components creating primary and secondary loops. In the former case, this ensures the presence of a minimum total system volume specified by the AWHP manufacturer. In the latter case, this decouples the operation of the outdoor unit from the operation of the indoor unit(s) and is typically done to prevent short cycling of the compressor by providing adequate thermal capacitance, but also enables complex zoning and simultaneous space conditioning and DHW production. More detail and figures showing these configurations can be found in Section V under Buffer Tanks.

In general, using a buffer tank for primary/secondary separation is not required or recommended when using properly sized AWHPs with variable speed compressors and pumps because they regulate their capacity in proportion to the load. However, if the system is zoned and the load on the smallest zone will be less the minimum capacity of the VC-AWHP, a buffer tank in the primary/secondary configuration should be used. Additionally, if the AWHP is serving DHW loads as well as space conditioning, a buffer tank can be used to allow for simultaneous space conditioning and DHW production. In that in mild climates where design conditions don't call for long run-times DHW operation can happen between heating or cooling cycles. However, if radiant delivery is used in this configuration, a buffer tank should be used. Radiant systems do not cycle as frequently or as quickly as forced air systems. Some single-speed heat pumps have built-in buffer tanks. Installation manuals should be consulted to find the recommended size of the buffer tank.

In planning the project, it is important to identify where tanks can be placed. To minimize piping length they should be located between the AWHP and distribution equipment. To minimize heat losses and to prevent weathering of insulation and jacketing they should not be located outdoors.

Indirect Water Heater

If the AWHP is to provide domestic hot water and replace a gas or electric water heater, then it would be advisable to install a water heater that has a larger storage volume than the existing gas water heater. In most places, code requires recirculated HVAC distribution water to be separate from domestic water. Indirect water heaters circulate water from a boiler or heat pump through a heat exchanger that transfers heat to the domestic water (see Figure 9). The larger storage volume is needed because the heat pump's ability to heat water is limited by the capacity of the heat exchanger, and its output must be shared with heating or air conditioning needs. Space requirements must also be planned for. As an example, one 80-gallon indirect water heater has a 26-inch diameter and a 6-foot height compared to the 20-inch diameter and 5-foot height of a typical 40-gallon gas water heater.

Thermal Storage

It is possible to add a water storage tank and use the heat pump to "charge" the storage so it can be used to provide cooling or heating during utility off-peak periods. To completely shift loads between the on-peak hours of 4 to 9 PM may require more than 500 gallons. This can be a complex undertaking and is best engineered by a designer experienced with the storage vessels, piping, and controls required. If the concrete floor is used for heating and cooling (radiant distribution) then it can be effectively used for thermal storage, but minimal carpeting should be used and wood and vinyl floor coverings must be avoided to prevent moisture damage.

Piping Connections and Routing

Central air conditioners and conventional heat pumps use copper refrigerant lines to connect the "outdoor unit" that contains a compressor and coil to the indoor refrigerant coil that is mounted on the furnace or installed in an air handler. Contrastingly, AWHPs can be connected to indoor equipment using inexpensive and installer-friendly cross-linked polyethylene (PEX) pipe. Rated to carry water as hot as 180°F and corrosion proof, PEX is much easier to install because it is flexible, does not require soldering, and can be connected using push-fit ("shark bite") fittings. PEX pipe is available with or without an oxygen barrier. Particularly if there are any components that have ferrous (iron or steel) parts exposed to the circulating water, an oxygen barrier is needed to minimize corrosion. "PEX-AL-PEX" has an aluminum inner layer that serves as an oxygen barrier and also allows the pipe to retain its shape when bent. Piping can be run through attics or crawlspaces but must be insulated to prevent heat loss in winter and heat gain in summer. Condensation on un-insulated pipes carrying chilled water can also cause moisture damage.

IV. Initiating the Project

Homeowner Perspective

In preparation for obtaining quotes for services, the following information should be gathered:

- Description of the house including age, square footage, number of stories, number of bedrooms, and information on any energy upgrades that may have been completed
- Type and approximate age of the existing heating & cooling equipment and ducts
- Location of the furnace (for example indoor closet, garage, attic)
- Cooling capacity of the existing air conditioner (can usually be determined from the model number located on the outdoor unit)

The following steps are good practice in any home improvement project involving replacement of heating and cooling equipment and other upgrades.

1. Consider completing home energy upgrades that will affect the sizing of new equipment. At this stage it would be important to engage an energy consultant to complete an analysis of the house that shows the impact of various energy improvements such as sealing air leaks between the attic, crawlspace, attached garage, and house, increasing attic insulation depth, insulating walls and floors, installing properly sized and insulated ducts and ventilation systems, and window replacement. Any such improvements will affect heating and cooling loads. This analysis should include ACCA Manual J, D, S, and T calculations as applicable. If the HPWH is to be used for water heating, a hot water use analysis should be completed and consideration should be given to how the time required for hot water to be delivered to the tap can be reduced, for example by locating the water heater centrally or shortening piping runs. The same consultant can provide the required Title 24 compliance documents and may be able to develop a rough cost estimate for the improvements.
2. Find a Home Improvement Expert[12] and/or HVAC contractor that has experience installing AWHP systems. Ideally, this will be a firm that provides design as well as installation services. For more complicated systems a hydronic systems designer should be engaged. A good way to find experienced professionals is to search the DOE website[13] for experts in your area and ask equipment suppliers.
3. Obtain cost estimates for the work, utilize DOE contractor checklists[14] in your official work agreement, and require that contractor(s) obtain all code-required permits and inspections.

---

[12] https://basc.pnnl.gov/home-improvement-expert

[13] https://basc.pnnl.gov/home-improvement-expert/partner-map

[14] https://basc.pnnl.gov/home-improvement-expert/checklists

Contractor Perspective

Assuming the homeowner has requested the installation of an AWHP and provided the information described above, the next step is to prepare a bid for the work. A visit to the site to understand the circumstances of the work is essential, for example where equipment is to be located, verification of sufficient space and access, how piping can be routed, and the adequacy of the existing electrical service.

Especially if the contractor is relatively inexperienced with AWHP systems then it would be advantageous, in advance of preparing a bid, to seek assistance from an experienced design professional. Equipment suppliers are usually willing to review or even provide designs. The design process should include sizing calculations, drawings, and a detailed equipment list. Using accurate sizing calculations for equipment selection and pipe and pump sizing will protect both the contractor and the homeowner against poor performance and the additional expenses needed to correct them.

Particularly for more complex projects, it is highly advisable that either the owner or the contractor retain an experienced designer. This will provide the owner with greater confidence that the system will meet comfort and energy savings expectations and it will improve the accuracy of the bid. Some designers also provide the necessary Title 24 compliance documents that will be needed as part of the permitting process. The Title 24 consultant must hold a Certified Energy Analyst certificate and will be familiar with what forms are required for permitting as well as required inspections.

V. Hydronic System Design

Load Calculations

The first step in designing a system is to calculate heating and cooling loads. Results will determine air and water flow rates for sizing air handlers, ducts, piping, and pumps. ACCA Manual J or software based on that method should be used to ensure that each room or space receives the proper amount of heating and cooling. For systems with central air handlers and ducted air delivery, ACCA Manual D methods should also be used to properly size the ducts. ACCA lists several approved software-based sizing applications[15]. Inputs to these applications include:

- Building orientation
- Wall, roof, and floor u-values of exterior walls
- Window u-values and solar heat gain coefficients (SHGC)
- Floor areas and volumes of each room
- Building air leakage rate
- Duct insulation R-value
- Indoor “design” temperatures (typically 68°F for heating and 75°F for cooling)
- Outdoor “design” dry-bulb temperatures from California Title 24 Part 6 Appendix JA2.[16]

For ducts located in the attic, load calculations must include duct air leakage and thermal losses. ACCA Manual S and T calculations should be completed. When duct systems are replaced or modified, this is

---

[15] https://www.acca.org/standards/approved-software

[16] https://www.energy.ca.gov/sites/default/files/2021-06/CEC-400-2018-021-CMF.pdf (Archive)

an opportunity to improve efficiency by shortening duct runs and reduce their surface area by moving registers to interior instead of exterior walls.

Designing an efficient hydronic Mixed-Air System[17] with lower temperature difference[18] between room and supply air than is typical for forced air furnaces dictates careful attention to terminal device selection. Excellent room air mixing and occupant comfort comes from selecting the proper volume, velocity and throw distance from the supply outlet so that the higher velocity supply jet remains in the non-occupied (within 2' of ceiling) space overhead. Maximum comfort is achieved when the room air in the occupied space is kept moving very slowly and imperceptibly.

Selecting a Heat Pump

Clearly, the chosen heat pump must have sufficient capacity to meet the total building heating and cooling loads at the local outdoor design temperatures. When heat pumps are used to heat domestic water they either deliver space heating or water heating but not both simultaneously, so in most cases only the space heating and cooling loads needs to be considered. A safety margin of at least 10% will reduce the risk of under-sizing, and oversizing may result in short cycling and reduced performance. A safety margin of at least 10% will reduce the risk of under-sizing, and oversizing may result in short cycling and reduced performance.

The next step in selecting a heat pump is to obtain performance data from the manufacturer on heating and cooling capacities over a range of outdoor temperatures.[19] Table 1 illustrates an expanded performance table listing heating capacities (in Btu per hour).

Table 1: Typical AWHP Heating Capacity Table

Leaving Water Temp °F	Outdoor Temperature °F				
	26	30	34	38	42
95	25,716	27,079	28,589	30,249	32,057
100	23,973	25,340	26,834	28,456	30,206
110	22,137	23,502	24,974	26,552	28,237
120	20,353	21,722	23,177	24,718	26,346
130	18,527	19,767	21,087	22,486	23,964

At a minimum, heating and cooling capacities that exceed Manual J calculated loads must be obtained at the outdoor and water temperature ranges used for the design. The outdoor design temperature depends on the location. The recommended supply water temperatures are 120°F for heating, and 50°F for cooling. If performance data at these conditions is not covered in manufacturers' literature, then it is possible to interpolate or extrapolate capacities, though this carries the risk of assuming liability for an under-sized heat pump. The manufacturer should be willing to certify that the equipment can meet specific design conditions even if they are not covered in published literature.

Heat pumps that are currently certified by the California Energy Commission are listed in the MAEDBS. See Footnote 4 for a link to the database. The integrated part load value (IPLV) is analogous to SEER

---

[17] ASHRAE. *ASHRAE 2009 Handbook—Fundamentals*, Chapter 20, Space Air Diffusion. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2009

[18] 15F to 25F maximum difference between room and supply air recommended for Mixed-Air System whereas furnaces are typically 35F to 80F difference.

[19] For radiant systems lower heating and higher cooling water temperatures can be used.

ratings for air-to-air heat pumps and air conditioners, so selecting a unit with a high IPLV will ensure good seasonal performance. Selecting a variable speed heat pump (Outdoor Fan Motor Design = Variable-Speed) can reduce the cost of the system by eliminating the need for a buffer tank and will reduce short cycling. (See the section Selection of Other Components for more information on buffer tank sizing and refer to the manufacturer's installation instructions.) The MAEDBS lists residential scale AWHPs with capacities from about two to five tons. Some manufacturers allow multiple heat pumps to be connected in parallel so that larger homes can be served.

The most common AWHP type is the "monoblock", which packages the refrigerant-to -water heat exchanger inside the outdoor unit. This type eliminates the need to run refrigerant pipe and saves space. "Split" system types require installation of the separate heat exchanger which is packaged with hydronic components inside the building. The heat exchanger and refrigerant lines must be charged with refrigerant on site, requiring the charge to be HERS-verified, whereas monoblock systems are factory charged. One advantage of split systems is they eliminate the risk of freeze damage to outdoor pipes, but in cold climates, monoblock systems can be protected by using an anti-freeze solution.

Other Design Choices

Two-Pipe or Four-Pipe?

Many commercial buildings use "four-pipe" systems which supply heating and cooling through separate piping. Four-pipe systems enable isolation of chilled and hot water circuits and provide the ability to simultaneous deliver heating and cooling. That ability is very uncommon in residences except those that have two or more separate heating and cooling systems, and they run the risk of fighting each other which is very energy-wasteful. AWHPs can change modes quickly and easily supply heating in the morning and cooling in the afternoon using a two-pipe system. This eliminates a considerable amount of expense for piping, multiple coils, and other accessories.

Forced Air or Radiant?

Radiant heating is well recognized for its superior comfort, quiet operation, and efficiency but there are tradeoffs as shown in Table 2.

Table 2: Forced Air and Radiant Distribution Pros and Cons

	Forced Air	**Radiant**
Advantages	• Latent as well as sensible cooling • More familiar to HVAC contractors • Probably be less expensive	• Pipes require almost no space • Pipes have much lower loss than ducts • Pumps use less energy than fans • Easy to zone • More moderate water temperature = higher heat pump efficiency • Potentially better comfort • If installed in slabs provides off-peak storage
Disadvantages	• Duct loss • Space requirements for ducts • High fan energy relative to pumps • Difficult to zone	• No latent cooling • Likely more costly in retrofits • Limited products available • More disruptive installation in retrofits

Radiant distribution is an excellent solution for new homes built on slab foundations particularly if carpeting is kept to a minimum and slabs are insulated on the edge (as required by code) and underneath. It is relatively inexpensive to install tubing in the slab, and the floor can be used to store cooling to avoid running equipment during on-peak cooling periods.

Radiant ceiling panels can be retrofitted but they tend to be expensive and there is a risk of damage from condensation when they are used for cooling. These two factors make them less desirable for retrofit applications.

Buffer Tank or Direct Delivery?

Buffer tanks add thermal capacitance to the system and should always be used with single speed and two speed AWHPs to minimize short cycling of compressors. They are less likely to be needed when using a VC-AWHP, especially in single zone systems, or if the load on each individual zone is within the VC-AWHP’s range of modulation. Buffer tanks are also important for systems that have relatively small zones that would cause short cycling when the load on the heat pump is significantly reduced, or if simultaneous space conditioning and DHW production is required.

Single or Multiple Zones?

One of the greatest benefits of hydronic systems is that they are easy to zone, that is, that they deliver heating and cooling to individual spaces controlled by thermostats in those spaces. Zoning improves comfort and can reduce utility bills. With traditional ducted systems, zoning is achieved using duct dampers. These are still an option for ducted hydronic systems, but zoning can also be achieved by using multiple fan coils, air handlers, or radiant loops, with a motorized zone valve on the supply to each to enable or disable flow through the loop. Examples of zoned configurations include using multiple fan coils (such as multiple hydronic heads in each room) or more than one ducted air handler (such as an upstairs ducted coil and a downstairs ducted coil).

Best practice for zoning is to use the “home run” plumbing configuration, where each hydronic loop starts and ends at the same point, typically on a manifold. This makes for easy zoning, as all of the zone valves are at the same location, and there are many manifolds available with integrated zone valves. Manifolds also often integrate other necessary components for a hydronic system, including air separator and expansion tank connections, pressure gauges, and flow rate indicators. Be sure to size the manifold for the required flow of each zone. Manifolds can also be site built using fittings, which may be more economical if there are only two zones or a primary/secondary water loop configuration is being used.

Zoning traditional air-to-air systems using duct dampers typically results in reduced airflow, reduced efficiency, and reduced equipment life, which is why California Title 24 Part 6 requirements for zoning are quite strict. However, with hydronic systems this can be avoided by using multiple fan coils or a buffer tank with a variable speed ducted air handler that offers zoning control options using motorized duct dampers. Examples of variable speed fans compatible with duct zone dampers include the Aermec MZC, iFlow AHU, and Energy Saving Products LV-Z.

Air Handler or Fan Coils?

Air handlers are used in “central” systems and are ducted to each room or space from the air handler location. Fan coils are distributed and may either serve a single space or can be ducted to serve other nearby rooms. Air handlers are generously sized to provide sufficient airflow and pressure to overcome the resistance of ducts and terminal devices for an entire home, whereas fan coils are smaller and sized to typically serve fewer rooms and devices, or individual zones of a home. Fan coils can be installed in small closets, lowered ceiling spaces, or mounted in the ceiling (“cassette”). When used for cooling, both fan coils and air handlers must include condensate drains that are terminated to outdoors or to a sanitary drain or sink. The decision of which to use depends on whether the house already has a central system and well designed and insulated ducts in excellent condition. Space available for fan coils and the importance of having separate zones, and cost and performance are other factors.

What About Radiators?

Wall-mounted panel radiators can be used in heating-only systems, but they may consume a considerable amount of wall area due to their lower output at typical AWHP supply temperatures. Since they are made of steel they will corrode unless inhibitors are added to the circulating fluid, and PEX piping must include an oxygen barrier. Traditional baseboard radiators cannot be used because of their low capacity for cooling and lack of condensate drains.

Piping Materials and Fittings

Since the 1990’s cross-linked polyethylene (PEX) has become the piping material of choice for hydronic systems as well as for hot and cold potable water systems. PEX is less expensive than copper, is resistant to corrosion, and because it is flexible it reduces the need for elbows. A variety of fitting types are available that make installation fast and leak-free.

Some PEX products include a coating that reduces the infusion of oxygen through pipe walls. It is important to use this “Barrier PEX” if there are any components that have exposed steel or iron (ferrous materials) including pumps, fittings, heat exchangers, and expansion tanks. Though non-ferrous components such as pumps and tanks are more expensive, to reduce maintenance cost it is highly recommended that only non-ferrous materials such as copper, brass, bronze, and stainless steel be used. This approach also eliminates the need for corrosion inhibitors, many of which are toxic and hazardous to the environment.

Selecting Air Handlers and Fan Coils

Air handlers and fan coils (and radiant panels if used) should be sized to meet the greater of the Manual J D S heating or cooling load for the spaces they serve with a 10 percent or greater safety margin. To minimize heat pump short cycling, they should also match the maximum capacity of the AWHP as closely as possible. Optimal heat pump supply water temperatures are 120°F for heating and 50°F for cooling. This provides a balance between heat pump efficiency and the size and cost of coils – larger coils are needed for more moderate water temperatures, but heat pump efficiency declines at higher heating and lower cooling water temperatures.

Air handlers and fan coils should be sized using their rated heating and cooling capacities for the specific entering water temperatures to be delivered by the AWHP and flow rates. Unfortunately, this information can be difficult to obtain. Manufacturers’ data can be interpolated or extrapolated. Extrapolation is riskier, especially for cooling, because the ratio of sensible to total cooling capacity changes with water temperature and water and air flow rates.

For sizing purposes, the minimum water flow rate should be 0.20 to 0.25 GPM per 1000 Btuh of capacity and airflow should exceed 400 CFM per ton (12,000 Btuh) of heat pump capacity. For example, for a house with a two-ton (24,000 Btuh) cooling load the air handler should be able to deliver at least 800 cfm and the piping and pump should be sized for 4.8 to 6.0 gpm. To avoid the need to use an overly large pump the water pressure drop through the air handler or fan coil should ideally not exceed 4 psi (9 feet w.c.) at the recommended water flow rate.

Heating Capacity

Manufacturers of hydronic air handlers and fan coils typically provide data on heating capacity at specific entering water temperatures and airflow rates. Performance data may only be available at entering water temperatures higher than 120°F because they are traditionally have been used with boilers where high water temperatures are available. The capacity can be estimated by extrapolating to lower water temperatures.

Cooling Capacity

Sizing air handlers and fan coils for cooling is more complicated. Chilled-water coils are (or should be) rated for total capacity and sensible capacity[20]. Also, since most air handlers have been developed for heating applications instead of cooling with chilled water, finding cooling performance data for coils can be challenging. AWHP manufacturers may be able to provide cooling ratings of air handler products they use or recommend.

Coil capacities at typical AWHP supply water temperatures are generally much lower for cooling than for heating. For example, the two air handlers used in the Design Example have cooling capacities at an entering water temperature (EWT) of 50°F that are slightly more than 50% of the heating capacities at a 120°F EWT.

Coil cooling capacities are usually rated at indoor conditions of 80°F dry bulb and 67°F or 62°F wet bulb temperatures. In dryer climates and at higher chilled water temperatures there is less moisture removal and more of the capacity is devoted to lowering the temperature of the air and less to condensing water, in other words a higher sensible heat ratio. To improve accuracy of sizing, coils should be selected based on rated cooling capacity at 50°F entering water temperature, though this information may be difficult to find. More information on this topic is provided in the Design Example.

Radiant Panel Sizing

Radiant ceiling panels can be sized using formulas provided by panel manufacturers and are based on either the entering water temperature or the average of entering and leaving water temperature.

Equation 1 and Equation 2 can be used to obtain a rough estimate of the panel area required for heating and cooling respectively using Manual J calculated loads. Performance can vary significantly by product and precise ratings should be obtained from manufacturers. If a fan coil is to be used to dehumidify indoor air its latent cooling capacity (total– sensible) at the appropriate entering chilled water temperature should exceed the calculated total cooling load from Manual J minus the radiant panel cooling capacity.

---

[20] Total capacity includes sensible cooling of air as well as removal of moisture from the air (latent cooling). Sensible capacity divided by total capacity is the “sensible heat ratio” and varies from about 60% to 100% depending on the wet bulb temperature of entering air and other factors.

Equation 1. Radiant panel area for heating.

$$Panel\ Area\ for\ Heating\ (ft^2) = \frac{Heating\ Load}{0.75 \times (T_{water} - T_{room})}$$

quation 2. Radiant panel area for cooling.

$$Panel\ Area\ for\ Cooling\ (ft^2) = \frac{Sensible\ Cooling\ Load}{0.90 \times (T_{water} - T_{room})}$$

A total flow rate of 0.20 gpm per 1,000 Btuh can be used for radiant systems for pump sizing purposes, but the flow through individual panels should be maintained as recommended by the manufacturer[21]. Panel flow rate can be adjusted by changing the number of panels that are on a single circuit or loop. For example, increasing the number of panels on a loop will decrease the number of parallel loops and will increase the flow rate.

Sizing panels for cooling can be done using the sensible cooling load only, but provisions must be made to control indoor moisture to prevent condensation on panel surfaces. Controls are available from some manufacturers that modulate water temperatures to prevent condensation by ensuring the supply water temperature is always above the room dewpoint temperature.

Calculating Water Flow Rates and Pipe Size

The goals of selecting the correct flow rates and pipe sizes is to ensure that the heat pump and each terminal unit (air handler, fan coil, or radiant panel) receives adequate flow, to minimize friction loss in piping, and to accurately size pumps. Keeping the total pressure drop through piping, fittings, and air handler/fan coils below about 20 ft. w.c. (about 9 psi) will permit use of smaller, more efficient pumps. For larger houses small pumps may be used instead of zone valves.

For single air handlers, it is only necessary to calculate the friction loss through the air handler and connecting piping. For multiple terminal units the friction loss of the most restrictive circuit or branch must be determined (this is usually the fan coil that is longest distance from the heat pump). Flow rates are calculated using Equation 3, which assumes a 10°F temperature change through the system. The capacity is the greater of the heating or sensible cooling capacity from Manual J.

Equation 3. Water flow rate.

$$\text{Flow Rate } (gpm) = \frac{\text{Capacity (BTU/}hour\text{)}}{5000}$$

Use the following steps to size piping:

1. Lay out the location of the heat pump and air handler, fan coil, or radiant panel terminals on a plan.
2. Determine the “round trip” lengths of all mains and branch circuits including supply and return lines. For an air handler there will be only the mains. Be sure to include supply and return pipe

---

[21] For optimal heat transfer in radiant panel systems the flow rate should be maintained in the turbulent range, which varies with pipe diameter and water temperature. For example, the flow rate of 50°F water in ½” pipe should be at least 0.9 gpm to be turbulent. However, to keep pipe friction and pumping energy low, the flow rate through the loop of ½” pipe should not exceed about 1 gpm.

and horizontal and vertical lengths. Note that if 90° elbows or other restrictive fittings are used their "equivalent length" must be accounted for.

3. From the load calculations and using Equation 3, calculate the flow rates of each branch circuit. If the rated flow rate of a terminal unit is greater, use the rated flow rate.
4. Refer to the manufacturer's pipe friction tables [22] and select pipe diameters for each branch that result in a maximum velocity of 5 feet per second and note the pressure drop in feet per hundred feet of each branch from the pipe diameter and flow rate.
5. Multiply the pipe friction from Step 4 by the pipe length (divided by 100) in Step 2 and tabulate the resulting piping friction loss in feet for each individual branch or circuit and for the main.
6. From manufacturer specifications, obtain the friction loss of the heat pump at its maximum flow, and of each terminal unit. Add those to the friction losses for the branch piping serving each terminal unit.
7. Determine the maximum system friction loss by adding the friction loss of the main supply-return line to that of the branch circuit (with terminal unit) that has the highest friction loss. If the total friction loss exceeds about 15 feet w.c. it is advisable to select larger pipe sizes or for multizone systems, to consider separating the zones into separate pumped circuits.

Pump Sizing

Pump manufacturers provide charts that relate system friction loss (usually in feet water column of head) to flow rate. Examples from two pump manufacturers are provided in Figure 5. To select the correct size pump, locate the total flow rate (from Step 3) on the horizontal axis and the maximum friction loss (from Step 7) on the vertical axis. Place a point on the chart where they intersect and chose a pump that has a curve that is above that point. Choosing a pump that has a relatively flat slope will reduce the consequence of errors in friction loss calculations or changes in pressure drop due to opening and closing of zone valves.

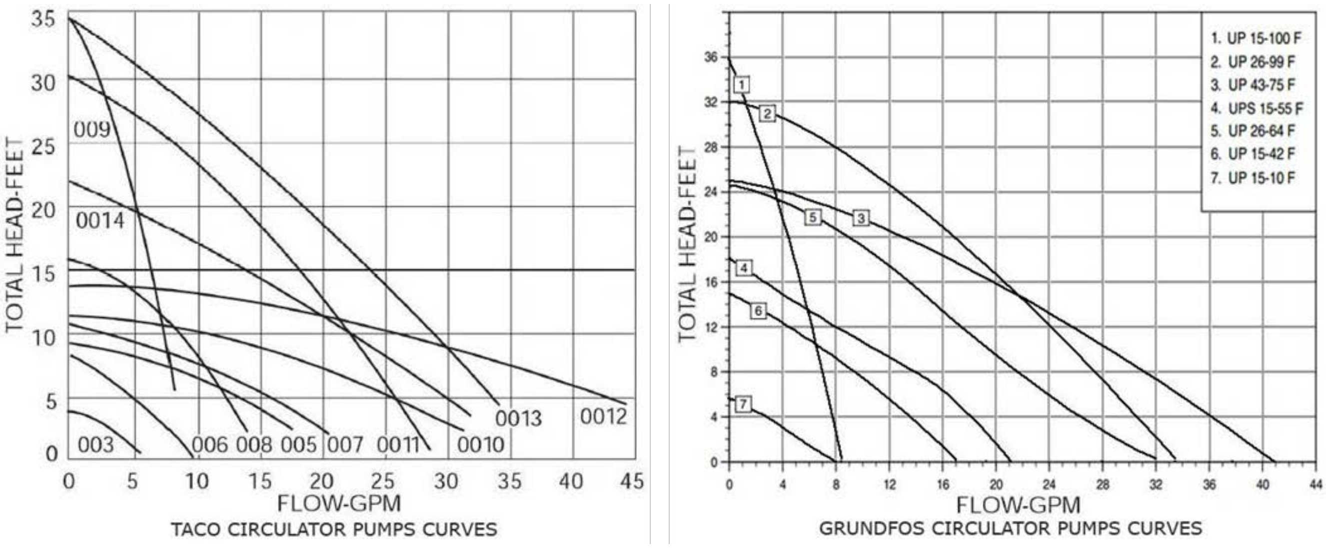


Figure 5: Typical Pump Sizing Charts

---

[22] Pipe manufacturers provide tools that simplify pipe sizing, for example https://tools.uponorpro.com/calculator/.

Several AWHP heat pump manufacturers include pumps with their systems. They should be able to a provide pump sizing chart that subtracts out the friction loss that occurs in the heat pump heat exchanger or provide the friction loss of the heat exchanger which should be accounted for in Step 6.

A more precise way to select a pump is to plot a "system curve" which represents the head that can be expected over a range of flow rates using the following equation:

Equation 4. System head loss curve.

$$H_2 = H_1 \times \frac{{F_2}^2}{{F_1}^2}$$

Where: H_1 is the friction head determined at a flow rate of F_1

H_2 is the friction head calculated at a flow rate of F_2

This resulting curve can be overlain on the pump curve to find where they intersect, which is the expected operating point. In the Figure 6 example, the system curve is based on a head of 10 feet at a corresponding flow rate of 6 gpm. The pump curve is for a Grundfos UP 43-75. The two curves intersect at 9 gpm, which is the expected operating point.

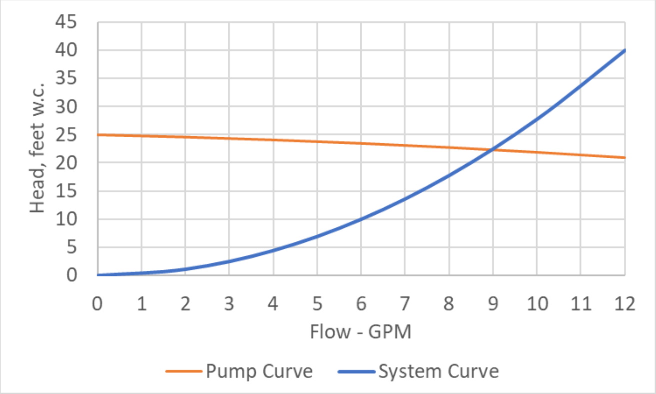


Figure 6: Pump Operating Point Example

If the pump provided with the AWHP is found to be inadequate to deliver the desired flow rate, a second pump can be added in series. When pumps are installed in series their pressure heads (at the same flow rate) are additive.

Though some manufacturers may require anti-freeze (propylene glycol) to prevent freezing of heat exchangers when systems are in cooling mode, it is not likely to be needed to prevent freeze damage to piping if outdoor runs are kept short and they are well insulated.

Glycol decreases the heat capacity and increases viscosity of the fluid. To compensate, pump sizing must be determined using a higher flow rate and a larger pump may be needed to overcome the lower heat transfer rate and added pipe friction. A 10 percent glycol solution will provide protection down to 26°F, which is sufficient for coastal and valley climates, but local weather data should be consulted. A 10 percent solution will require pump sizing to be based on a flow rate that is 2 percent higher than for water only. Larger pumps may be required for higher levels of freeze protection.

Selection of Other Components

Buffer Tanks

Piping and distribution systems may or may not contain sufficient water (which serves as capacitance) to prevent short cycling. Particularly if a single speed heat pump is being used, and/or if multiple fan coils resulting in a significant mismatch between the load and the heat pump capacity. Electric water heaters with 1" NPT heating elements can serve as low-cost buffer tanks.

Buffer tanks may either be placed in series with the main supply-return piping as shown in Figure 7, or in a "pump in-pump out" configuration as shown in Figure 8. In either case, one or more ducted air handlers could be substituted for the fan coils. The series arrangement shown accommodates the decreased load when only one fan coil or air handler is operating.

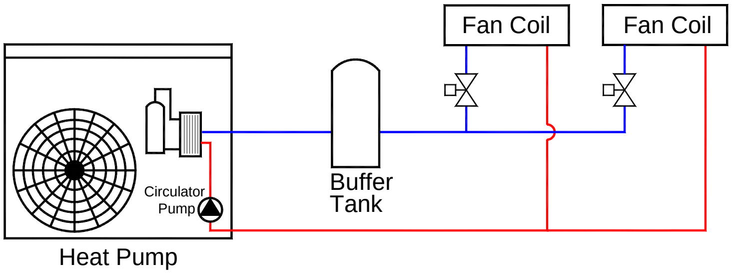


Figure 7: In-line buffer tank

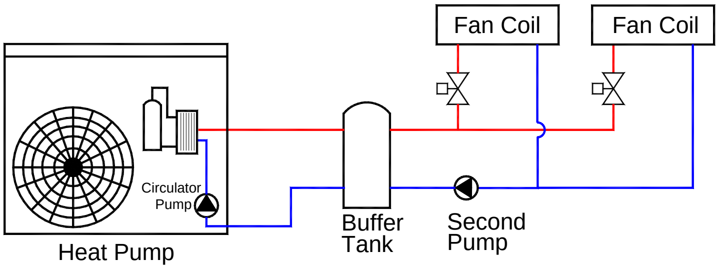


Figure 8: Pump in - pump out buffer tank

For the pump in-pump out configuration, the buffer tank temperature may be fixed or, to conserve energy, may be varied using outdoor temperature reset. Another application of buffer tanks is to use them for dual temperature control. For example, if dehumidification is needed to prevent condensation on radiant ceiling panels, the buffer tank can be used to provide lower temperature water for a dehumidifying fan coil. Vastly oversized pump-in, pump out buffer tanks can also be used to provide off-peak thermal storage.

The following equation can be used to determine whether a buffer tank is needed and what volume of water it should contain. *Minimum Volume* includes the volume of water in the system and in the buffer tank. *Min. Heat Pump Capacity* is the rated capacity for single-speed AWHPs or the lowest capacity for variable speed or multi-speed AWHPs. This calculation conservatively assumes there is little or no load on the system. If the system volume without a buffer tank is greater than the *Minimum Volume*, then a buffer tank is not necessary, unless the manufacturer specifies a larger minimum system volume in the AWHP installation manual.

Equation 5. Minimum total system volume.

$$Minimum\ Volume = \frac{Min.\,HP\ Capacity \times Min.\,Cycle\ Time\ (minutes)}{60 \times \Delta T \times 8.3}$$

For example, let us say the project will use a two-speed heat pump with a maximum capacity of 48,000 Btuh with a 50% first stage turn-down. The system piping contains 6 gallons of water. The design calls for the heat pump to not cycle on and off more frequently than every 5 minutes and to allow a maximum 10°F water temperature swing. The total volume needed will then be:

50% X 48,000 x 5 / (60 X 10 X 8.3) = 24 gallons

Since the system contains 6 gallons, a tank with a capacity of 18 gallons or greater will be sufficient.

In another example, the project will use a variable capacity AWHP with a capacity range of 12 to 24 kBtuh. The fan coil and AWHP contain 1 gallon each, and the system piping contains 8 gallons for a total system volume of 10 gallons. Using the same parameters as the first example (5 minute cycle time, 10 degree delta-T), the minimum system volume necessary would be 12.05 gallons. However, the manufacturer installation manual specifies a minimum system volume of 15 gallons. Either way, there is not enough volume in the system to prevent short cycling. A small tank of at least 5 gallons should be added on the return to add additional volume to the system.

Water Heaters

An AWHP can provide domestic hot water heating by connecting to an "indirect water heater" that isolates the low-pressure water used in the heating-cooling system from the higher-pressure potable water as shown in Figure 9. Due to the lower water temperatures AWHPs can produce relative to gas boilers, the water heater must have a heat exchanger with a large surface area. Indirect water heaters using a "tank within a tank" design are preferred because they can exchange heat even while the heat pump is not operating.

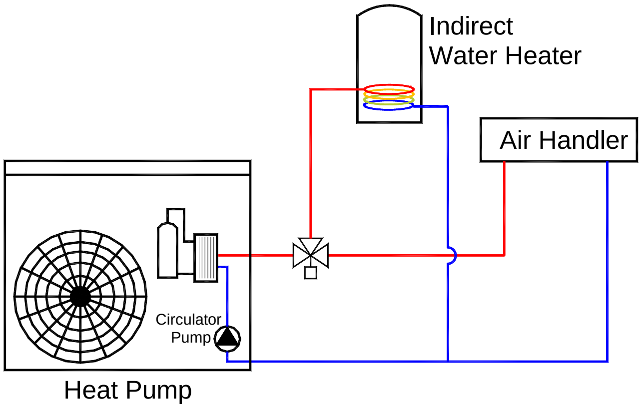


Figure 9: Integrated domestic water heating and space conditioning

Pumps

Several manufacturers produce "wet rotor" pumps that are water lubricated, have at least a 20-year life, are efficient, and have replaceable cartridges for easy maintenance. These are available in sizes from 1/40th to 1/6th horsepower, which meets the needs of practically any residential AWHP application. While more costly, using only pumps of bronze or stainless construction will provide longer life, lower maintenance, and avoid introducing rust to the water.

Zone Controls

Zoning can be accomplished by providing motorized zone valves as shown in Figure 7 and Figure 8. They are connected to a central control that receives thermostat signals and operates the zone valves. Some zone valves include an "end switch" that can be used to operate the pump and heat pump when the valve is fully open. For multizone systems manifolds are available that incorporate heat activated zone valves.

Expansion Tanks

As water in a system changes temperature, it expands and contracts causing the pressure to change. Expansion tanks absorb the pressure changes and avoid too low a pressure which can cause pumps to cavitate, or too high a pressure which can cause pressure relief valves to "pop off." Typical pressures in hydronic systems range from 12 to 30 psi.

Expansion tanks used in residential systems and most commercial systems include a rubber bladder that prevents the captive air in the tank from mixing with the water. The tanks are rated by total volume and "acceptance volume". Systems that circulate water without corrosion inhibitors should use tanks designed for potable water heating systems because they are lined and will last much longer. Tanks for water heaters are charged to about 50 psi, but the charge can be lowered by releasing the captive air using the Schrader valve attached to the bottom of the tank. A charge pressure of 12 psi is recommended.

Manufacturer sizing instructions for expansion tanks are typically for heating-only systems. The acceptance volume for systems having a temperature range of 50°F to 120°F and a pressure range from 12 to 30 psi can be estimated by multiplying the total system volume by 0.0113[23] and the minimum total tank volume can be estimated by multiplying the acceptance volume by 2.5.

Air Separation

When systems are initially filled, air can be trapped in the waterways and is also dissolved in the water. (As water is heated the air disassociates.) If the air is not removed it can airlock the pump or cause it to cavitate, potentially causing permanent pump failure. Several manufacturers offer air separators that capture and vent out air like the one pictured at right.

---

[23] Derived from the 1996 ASHRAE Systems and Equipment Handbook, p. 12.4.

Pressure Maintenance and Makeup Water

Hydronic systems are required to incorporate a pressure relief valve. Relief valves for designed for hydronic systems are set at 30 psi. Pressure-temperature relief valves used for water heaters are set at a pressure of 125 psi and must not be used.

If systems are leak free as they must be they do not require addition of water but pressure can be lost as air is vented out. The only time water needs to be added is to replace water lost during maintenance, for example following replacement of a pump. Makeup water systems are available that can be connected to a potable water supply. They include a pressure reducing valve, backflow preventer, and water shutoff. A simpler means of boosting pressure and adding water is to install hose bibbs for filling and draining using water hoses. Placing a shutoff valve between the hose bibb connections also allows the entire system to be flushed. A pressure gauge is a mandatory feature. The one pictured includes temperature as well as pressure readings.

VI. Design Example

The example house is an energy-efficient 2200 ft^2 two-story house with an attached garage. The first floor is 900 ft^2 and the second floor is 1300 ft^2. It was determined that each floor would be served by a separate ducted air handler.

1. Calculate Heating and Cooling Load

A Manual J calculation was used to calculate the loads (in Btuh), which are as follows:

Table 3: Calculated Heating and Cooling Loads for the Design Example

Level	Heating Load	Sensible Cooling	Total Cooling
First	13,500	10,800	11,368
Second	15,600	19,500	20,526
Total	29,100	31,326	31,894

2. Select Heat Pump

We see the total cooling load (31,894 Btuh) exceeds the heating load so we will use the cooling load for initial sizing, and we pick a heat pump with a cooling capacity of 34,000 Btuh at an outdoor design temperature of 95°F and at leaving water temperature of 50°F. It is a variable speed unit and its minimum capacity is 17,000 Btuh.

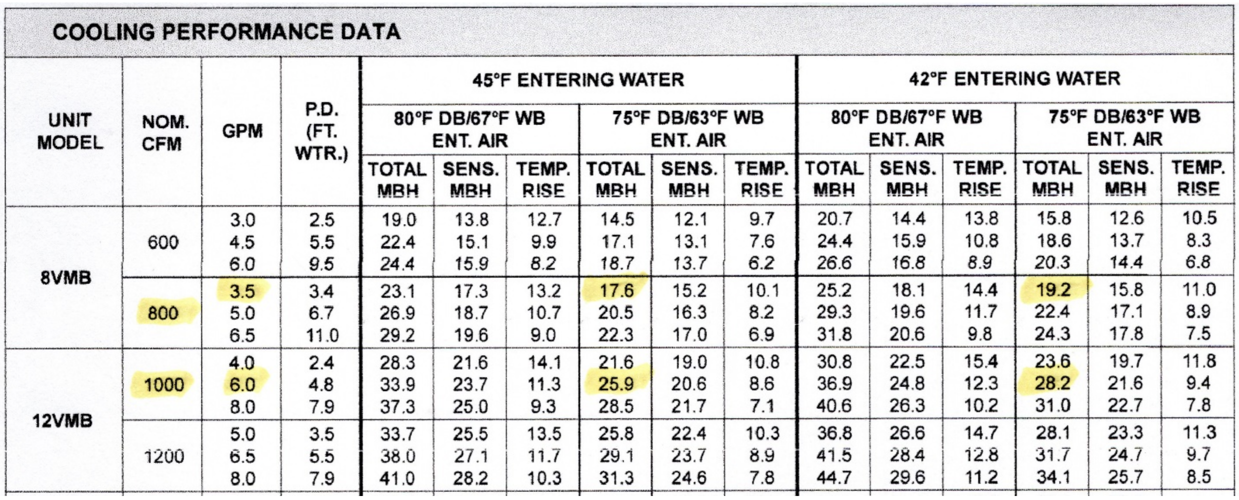
3. Select Air Handler or Radiant Panels

This example applies to forced air delivery, but radiant panels could also be used. When choosing an air handler with a single coil that will both provide heating and cooling it is best to select one that meets the cooling requirements, then verify it exceeds the required heating capacity. Using the calculated total cooling loads (just under 1 ton for the first floor and two tons for the second floor), the air handlers should be capable of delivering at least 400 CFM for the first floor and at least 800 CFM for the second floor, but actual airflows will depend upon coil sizing. Using Equation 3 water flow rates should be at least 2.3 and 4.1 GPM for the first and second floors, respectively, but again the selected flows should correspond to coil ratings.

Table 4 shows expanded ratings for two air handler sizes. It is rare that the calculated requirements for airflow, water flow rate, or entering water temperature (EWT) align with manufacturers' data. In this case we will use "nominal" airflows[24], of 800 cfm for the first floor and 924 cfm for the second floor, and water flows of 3.5 GPM for the first floor and 6.0 GPM for the second floor. Coil capacities higher than the loads were selected because the ratings in the table are for lower entering water temperatures than the 50°F we want to use and to provide a safety factor.

Since Table 4 only goes as high as 45°F entering water temperature (EWT) extrapolation must be used to estimate the capacity at 50°F EWT. We will use the capacities at 75°F entering dry bulb (DB) and 63°F entering wet bulb (WB) because the sensible heat ratios (SHRs) are higher. (As the entering water temperature increases so does the SHR because there is less condensation on a warmer coil).

Table 4: Typical Air Handler Expanded Cooling Ratings



COOLING PERFORMANCE DATA

UNIT MODEL	NOM. CFM	GPM	P.D. (FT. WTR.)	45°F ENTERING WATER						42°F ENTERING WATER					
				80°F DB/67°F WB ENT. AIR			75°F DB/63°F WB ENT. AIR			80°F DB/67°F WB ENT. AIR			75°F DB/63°F WB ENT. AIR		
				TOTAL MBH	SENS. MBH	TEMP. RISE	TOTAL MBH	SENS. MBH	TEMP. RISE	TOTAL MBH	SENS. MBH	TEMP. RISE	TOTAL MBH	SENS. MBH	TEMP. RISE
8VMB	600	3.0	2.5	19.0	13.8	12.7	14.5	12.1	9.7	20.7	14.4	13.8	15.8	12.6	10.5
		4.5	5.5	22.4	15.1	9.9	17.1	13.1	7.6	24.4	15.9	10.8	18.6	13.7	8.3
		6.0	9.5	24.4	15.9	8.2	18.7	13.7	6.2	26.6	16.8	8.9	20.3	14.4	6.8
	800	3.5	3.4	23.1	17.3	13.2	17.6	15.2	10.1	25.2	18.1	14.4	19.2	15.8	11.0
		5.0	6.7	26.9	18.7	10.7	20.5	16.3	8.2	29.3	19.6	11.7	22.4	17.1	8.9
		6.5	11.0	29.2	19.6	9.0	22.3	17.0	6.9	31.8	20.6	9.8	24.3	17.8	7.5
12VMB	1000	4.0	2.4	28.3	21.6	14.1	21.6	19.0	10.8	30.8	22.5	15.4	23.6	19.7	11.8
		6.0	4.8	33.9	23.7	11.3	25.9	20.6	8.6	36.9	24.8	12.3	28.2	21.6	9.4
		8.0	7.9	37.3	25.0	9.3	28.5	21.7	7.1	40.6	26.3	10.2	31.0	22.7	7.8
	1200	5.0	3.5	33.7	25.5	13.5	25.8	22.4	10.3	36.8	26.6	14.7	28.1	23.3	11.3
		6.5	5.5	38.0	27.1	11.7	29.1	23.7	8.9	41.5	28.4	12.8	31.7	24.7	9.7
		8.0	7.9	41.0	28.2	10.3	31.3	24.6	7.8	44.7	29.6	11.2	34.1	25.7	8.5

Extrapolating:

For the 8VMB at 800 CFM and 3.5 GPM we get:

Capacity at 50°F = 19.2 – (50 – 42) x (19.2 – 17.6) / (45 – 42) = <u>14.9 MBH</u>

For the 12VMB at 1000 CFM and 6 GPM we get:

Capacity at 50°F = 28.2 – (50 – 42) x (28.2 – 25.9) / (45 – 42) = <u>22.1 MBH</u>

These capacities exceed the 11,468 and 20,526 Btuh cooling loads by greater than 10%. This safety margin is especially needed because total capacity decreases as the SHR decreases. [25] Checking the heating ratings of these coils at an entering water temperature of only 100°F we see they have far more heating capacity than needed: 17,200 Btuh for the first floor unit (8VMB) and 24,100 Btuh for the second floor unit (12VMB).

---

[24] The table does not specify the static pressure associated with the nominal airflow. Best to be conservative.

[25] As manufacturers recognize the need for performance data at higher water temperatures, we may see ratings at 50°F or higher.

Radiant panel sizing can be simpler and can be done using Equation 1 and Equation 2 or ideally manufacturer ratings, but prevention of condensation must be addressed by the design.

4. Size the Piping and Determine Total Friction Loss

Refer to the steps provided in Calculating Water Flow Rates and Pipe Size. The total flow rate calculated using Equation 3 is 7.0 GPM and for the selected heat pump the maximum flow rate is 7.5 GPM. Though the coil ratings are at 3.5 and 6 gpm, or 9.5 gpm total, the assumption can be made that they will not need to operate simultaneously for very long and the maximum 7.5 gpm flow rate can be used for sizing the main piping. We used the Uponor tool (see Footnote 22) to find pipe sizes that would result in a velocity less than 5 ft/sec. and to calculate the friction losses. Measuring the pipes that we laid out on a scale drawing resulted in the lengths shown in Table 5. The round-trip lengths were multiplied by the calculated friction loss and the air handler friction loss was added to obtain the total loss for the two circuits serving the two air handling units (AHUs).

Table 5: Pipe Size and Friction Loss Calculations for Design Example

Air Handler	Pipe Size	Flow (GPM)	Velocity (ft/sec)	Friction Loss/100 ft	Pipe Length	Total Friction Loss (ft)	AHU Loss (ft)	Total Loss
AHU 1	3/4	3.5	3.18	8.15	76	6.2	3.4	9.6
AHU2	1	6	3.3	6.4	84	5.3	4.8	10.1

The main piping feeding the two circuits was sized at 1” (4.1 ft/sec). The distance from the heat pump to where the line splits into the two branches is 5 feet (10 feet total), and has a total friction loss of 0.9 ft. The heat pump friction loss provided by the manufacturer is 9.8 ft. at 7.5 GPM. Adding that to the greater of the two friction losses from the table, losses from the main, and to the heat pump loss gives a total head loss of 10.1 + 0.9 + 9.8 = 20.8 ft.

5. Select the Pump

The selected AWHP includes a pump that delivers 7.5 GPM at 24 feet of head, so that will meet the requirements of this application. Otherwise, a booster pump would need to be added to supplement the pressure head of the primary pump. Alternatively, two separate pumps could be provided to serve each air handler in lieu of installing zone valves.

6. Size the Buffer Tank

We first determine how much water is needed in the system to reduce short-cycling. We do not want the heat pump run time to be any less than 5 minutes, so using Equation 5 we get:

50% x 34,000 Btuh x 5 min. /(60 x 10 x 8.3) = 17 gallons

Documentation from the manufacturer states that PEX pipe contains 1.8 gal. /100 ft. for ¾” and 3.0 gal./100 ft. for 1”. Multiplying these by the pipe lengths we get 4.2 gallons. The heat pump and air handlers hold a total of 8 gallons and the expansion tank holds about 1 gallon for a total of 13.2 gallons. A 5 gallon buffer tank would increase the volume to 18.2 gallons and would add sufficient capacity to eliminate short-cycling.

7. Select Other Components and Prepare Schematic

A schematic of this example system showing a full complement of components is provided in Figure 10. The pressure relief valve and air separator should always be at the high point in the system. If a combination pressure/temperature gauge is used it should be on the discharge side of the heat pump. The buffer tank can go anywhere in the primary loop. The zone valves shown open when there is a thermostat heating or cooling call in the zone served by the air handler or forced air unit. The expansion tank should go on the suction side of the pump. The fill/purge valves allow the system to be flushed and purged of air prior to startup by closing the middle valve, attaching a hose connected to a water supply to the left hose bibb and a drain hose to the right hose bibb.

Some heat pump products may integrate components such as a pressure relief and air separator and expansion tank and may include valving for flushing and purging. Air vent valves (besides the one integral with the air separator) are not needed provided the system is thoroughly purged of air.

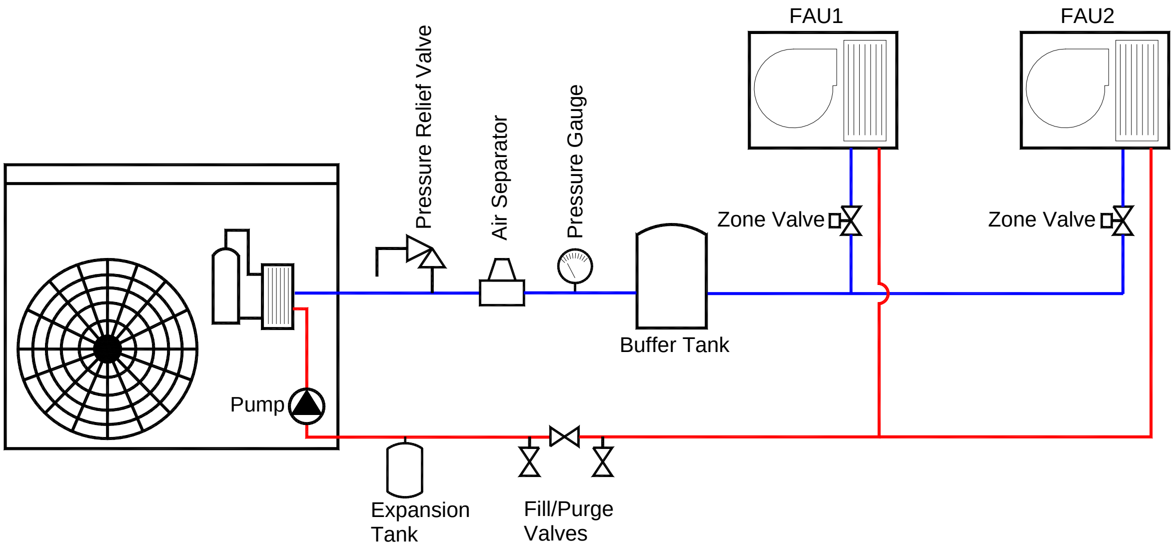


Figure 10: Example System Schematic

VII. Controls

Controls for heating-only hydronic systems are widely available but controls for heating and cooling systems, particularly zoned systems, are less common. Figure 11 shows a single zone control schematic which includes an optional provision for water heating. Note that his is provided as an example only. Every heat pump, air handler, and thermostatic control system is unique, and controls must be integrated in accordance with their particular requirements.

Though control features for each AWHP vary, most can be controlled using “dry contact” inputs to initiate heating or cooling operation or to activate domestic water heating. More advanced controls might include humidity control, reset of water temperature based on outdoor air temperature, and other features. Proper integration of control components is critical and should be reviewed with the AWHP manufacturer.

Some AWHP controls include logic that gives water heating priority. For example, if the heat pump happens to be operating in cooling mode and receives a call for domestic hot water heating, the heat pump switches to heating mode and the 3-way valve is signaled to divert flow to the indirect water heater. If not, that logic must be added. Relays and other external components are typically provided by the HVAC contractor.

There are at least two manufacturers of controls that can operate zoned systems to provide heating and cooling[26] and both require specialized thermostats. At least one air handler manufacturer[27] offers controls that can integrate heating and cooling as well as zoning. One radiant ceiling panel manufacturer provides a full set of controls that eliminate the risk of condensation by sensing dewpoint temperatures[28].

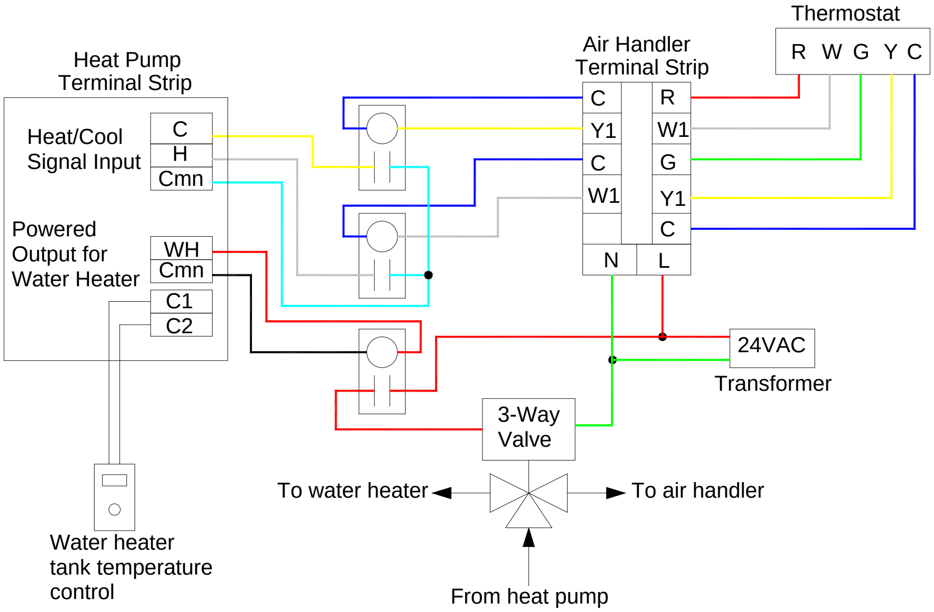


Figure 11: Example Control Schematic

VIII. Installation

Permitting and Energy Standards Compliance

Title 24 Compliance Documentation

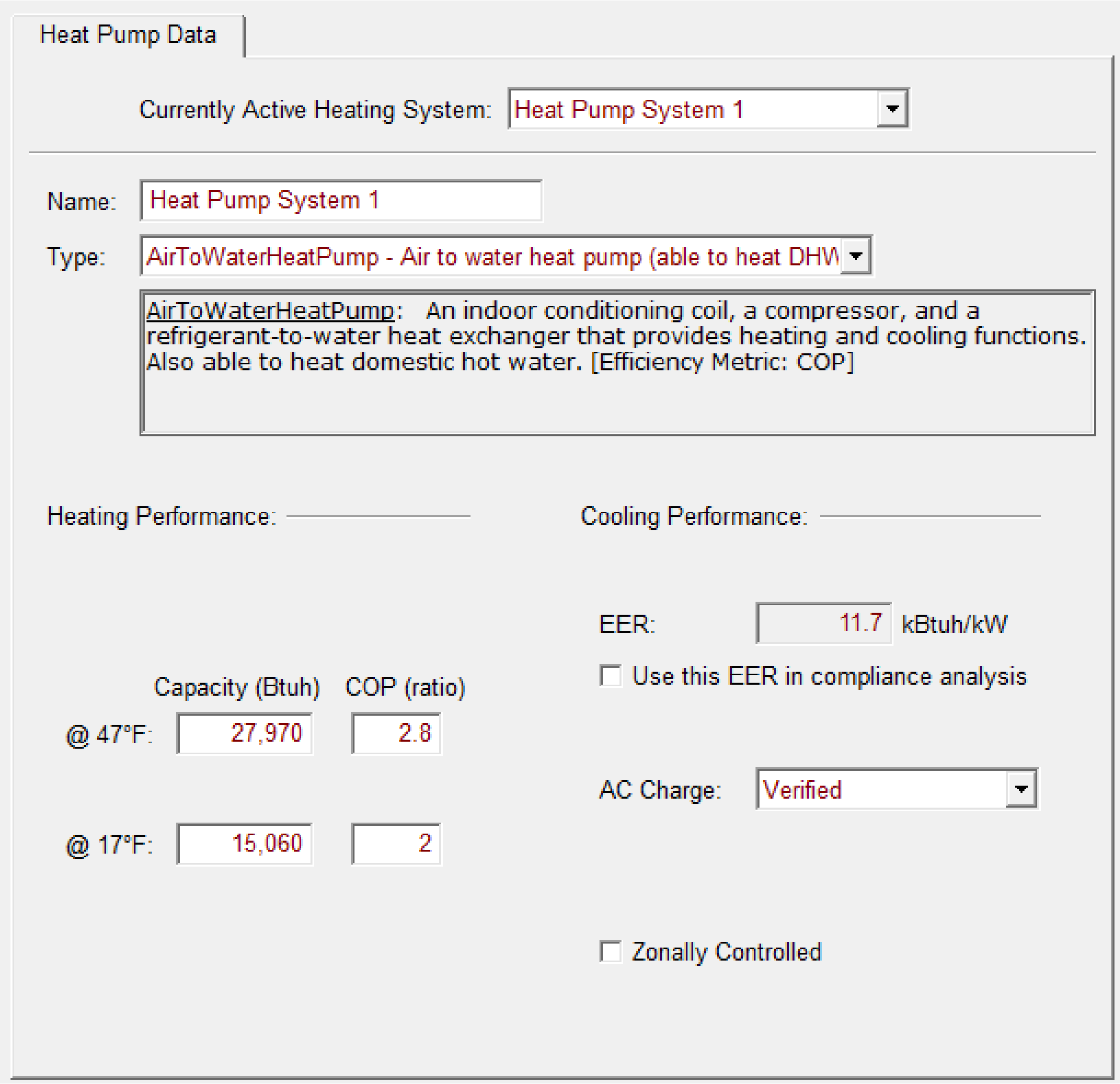
It is the responsibility of the contractor to file for a permit to install any new HVAC system and the permit application must include Title 24 compliance forms. Typically, equipment replacement for existing homes is handled using the “prescriptive path”, which ensures that equipment meets minimum federal efficiency requirements. Air-to-air heat pumps must have a minimum cooling efficiency (SEER) of 14 and a minimum heating efficiency (HSPF) of 8.2. These will increase to SEER 15 and HSPF 8.8 in 2023[29]. Because AWHPs are not rated the same way as air-to-air heat pumps the building official may require completion of Title 24 forms showing equivalent performance to standard air-to-air systems.

Air-to-water heat pumps are recognized in compliance software as a specific heat pump system type and certified compliance software such as CBECC-Res or EnergyPro can be used to demonstrate

---

[26] Watts-Tekmar (Model 406) and HBX Control Systems (ZON-0550)
[27] iFlow
[28] Messana
[29] https://www.eia.gov/todayinenergy/detail.php?id=40232

equivalency. The input form used by the 2019 version of CBECC-Res appears as shown in Figure 12. The EER and COPs are obtained from the Energy Commission's database (MAEDBS – see Footnote 4).



Currently Active Heating System: Heat Pump System 1

Name: Heat Pump System 1

Type: AirToWaterHeatPump - Air to water heat pump (able to heat DHW

AirToWaterHeatPump: An indoor conditioning coil, a compressor, and a refrigerant-to-water heat exchanger that provides heating and cooling functions. Also able to heat domestic hot water. [Efficiency Metric: COP]

Heating Performance:

	Capacity (Btuh)	COP (ratio)
@ 47°F:	27,970	2.8
@ 17°F:	15,060	2

Cooling Performance:

EER: 11.7 kBtuh/kW

☐ Use this EER in compliance analysis

AC Charge: Verified

☐ Zonally Controlled

Figure 12: CBECC-Res Input form for AWHP

Research conducted at a laboratory house maintained by PG&E has shown that AWHPs perform better than minimum efficiency air-to-air heat pumps, yet CBECC-Res results tend to show the opposite. A code change proposal was submitted for the 2022 Title 24 standards cycle[30], and the proposed compliance method will be implemented in an update to compliance calculation methods before the end of 2021. This change will treat single speed AWHPs the same as standard efficiency air-to-air heat pumps and will apply a 2 percent heating and 8 percent cooling savings factor to the prescriptive air-to-air heat pump energy use for variable speed AWHPs. This change will allow the prescriptive compliance path to be used in all cases and will provide additional compliance credit for variable speed systems if the performance path is used.

---

[30] https://title24stakeholders.com/measures/cycle-2022/enhanced-air-to-water-heat-pump-compliance-options/

Other Code Requirements

As with any HVAC installation, the requirements of adopted mechanical and electrical codes must be complied with. Where an AWHP is replacing an air conditioner or heat pump the same electrical service used for the existing equipment can be used for the AWHP provided the amperage rating does not exceed the amperage of the existing service. Where a furnace is being replaced, 240V service should not be necessary for the indoor air handler. Electric resistance heat is not needed when the AWHP is properly sized. In extreme heating climates, back up heat is better implemented on the hydronic side than on the air side, and can be either gas or electric.

The Building Efficiency Standards dictate that pipes carrying heated or chilled water must be insulated. For pipes carrying hot water (105-140°F) 1 inch of insulation (R-7.7) is required for pipes smaller than 1 inch and 1.5-inch-thick insulation is required for larger pipes. For pipes carrying chilled water (40-60°F) only ¾ inch thick insulation is required for pipes smaller than 1.5 inches. To prevent water damage resulting from condensation on chilled water pipes it is important that they be thoroughly insulated.

Replacement of equipment falls under Section 150.2(b) of the Title 24 Energy Efficiency Standards and the same rules apply for AWHPs as for any other equipment. For example, new ducts in unconditioned space must be insulated to R-6 or better and when more than 25 feet of duct is being replaced ducts must be sealed and tested (this decreases to 10 feet in 2023). Also, airflow must be verified and must be at least 300 CFM per ton of nominal cooling capacity. Factory charged equipment such as monoblock AWHPs do not need to have the refrigerant charge verified.

Manufacturer Installation Instructions

Instructions for different brands vary widely with respect to recommended flow rates, primary-secondary loops, use and location of buffer tanks, and requirements for connection to different distribution system types. Safety precautions described in the installation manuals should always be observed.

Provided good hydronic design practice is followed and adequate flow rates are maintained to all equipment, there are many acceptable ways to install these systems. However, to protect warranties it is prudent to not deviate from manufacturer recommendations. Controls packaged with air-to-water heat pumps are much more versatile and complex than for air-to-air heat pumps, and manufacturer instructions for making control settings should be carefully studied.

Equipment Placement

Heat Pump and Water Connections

The logical spot to place the AWHP is where the existing air conditioner is located. The existing electrical service for the existing air conditioner or heat pump, including the circuit breaker in most cases should be adequate to supply the AWHP. To minimize heat loss, piping runs to the house should be kept short. If they cannot be run directly through the wall into the house or crawlspace and must be extended upward into the attic, then they should be well insulated and protected by a sheet metal or wood enclosure. The heat pump must be installed on an equipment pad or wall mounted to keep it from sitting in pooling water caused by equipment defrost and frequent winter operation below the outdoor air dew point temperature.

The heat pump will have a condensate drain which should be terminated in a location that is well drained such as a dry sump. Using a well sloped ¾” drainpipe will help prevent condensate from freezing in the drain line and blocking flow during freezing weather.

Water piping at wall penetrations must be well sealed to protect against weather damage and insect intrusion. There are products made for this purpose, or a flashing plate can be used as shown in Figure 13. Where pipes pass through the flashing plate they should be sealed with a flexible, durable sealant such as polyurethane or polysulfide.

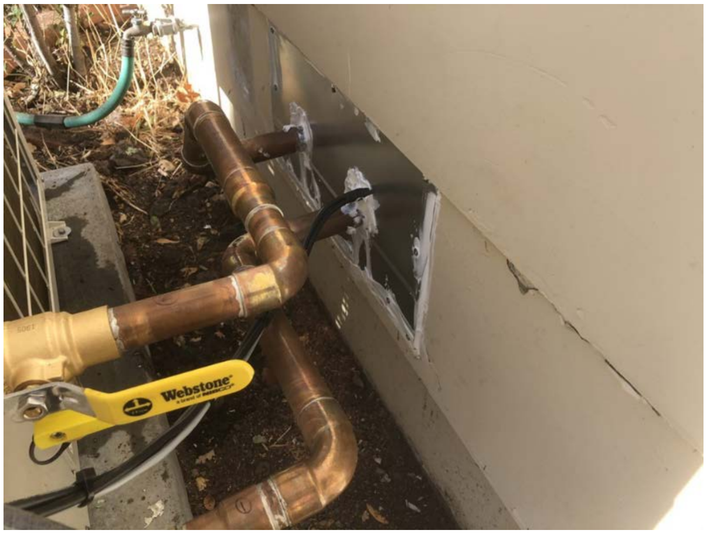


Figure 13: Sealing wall penetrations

Air Handlers and Fan Coils

If the gas furnace is being replaced by a ducted air handler, the air handler is likely to be physically smaller and able to fit in the space occupied by the furnace. It can use the same control wiring between the air handler and the thermostat and between the air handler and the outdoor unit, though more conductors may be needed for the latter.

To avoid the hot attic environment, fan coils are best installed in closets, dropped ceilings, or crawlspaces and connected to rooms using short duct runs. Ductless wall mounted fan coils and ceiling cassettes (similar to mini-split heads) are also available.

Ducts and Piping

Ducting

If an air handler is connected to existing ducting, the ducts should be tested for leakage and sealed. Sheet metal ducts have lower resistance to airflow than typically installed flexible ducts and should be retained if they were designed and installed well and can be adequately sealed and insulated. Ducts can also be sealed by a proprietary system of pressurization while injecting an aerosol that deposits at leakage points, a method that is particularly useful if ducts are inaccessible.

Flex ducts that are older and poorly insulated should be replaced with ducts that are installed in a fully extended state, have at least an R-6 insulation rating and are sized using ACCA Manual D. If duct replacement is combined with removal and replacement of attic insulation, then they can be lain over rafters or trusses and buried in insulation. Leaks in the ceiling can be sealed as part of the same process.

A common problem with existing homes is that return air grilles and filters are sized for old style fiberglass filters which have very low resistance to airflow. Current energy codes require filters with a rating of MERV 13 or higher which improve indoor air quality by removing small particles, but they have higher pressure loss, restrict airflow, and can increase fan energy use when replacement air handlers use the most efficient fan motors. Return air filter grilles should be sized for a velocity of not more than 200 feet per minute and for filter depths of two to five inches.

When distributed fan coils are installed, ducting should be routed though interior soffits, dropped ceilings, or crawlspaces. This avoids the notoriously poor distribution efficiency of unconditioned attic ducts.

Pipe Installation

Pipe must be installed in accordance with plumbing and mechanical codes. Copper pipe should be used between the heat pump and the house (see Figure 13), insulated, and covered with a weatherproof jacket. Most or all the remaining piping can be run with PEX. All piping should be insulated in accordance with Title 24 requirements. The common plumbing practice of burying uninsulated pipe under attic insulation may lead to water damage because the water vapor within the insulation will condense on pipes carrying chilled water.

IX. Commissioning

A very important step in the commissioning process is to flush all the piping to remove bits of solder and any other foreign material by forcing water through all system piping using hose connections as shown in Figure 10. This should be done at high pressure (connection to water mains or using a pump) to achieve high velocity flow. If zone valves are present, they should be opened one at a time. This process will also purge any trapped air from the piping and equipment.

Once flushing and purging is complete, ensure the expansion tank is set to about 12 psi and charge the piping to about 20 psi. Immediately inspect piping for leaks. The pressure should be checked after several days of operation because air entrained in the water will be vented off and the pressure will fall. If the pressure continues to fall, check thoroughly for small leaks.

Make all necessary control settings on the heat pump. This will require careful study of installation instructions because most systems have a variety of digital settings that may not be easily understood. Consult with the manufacturer or product rep as necessary.

Test the system in all control modes (heating, cooling, water heating) to ensure controls are functioning properly. If the heat pump is showing error codes such as low flow, trouble-shoot the problem and obtain assistance from the AWHP manufacturer’s technical support if necessary.

After the system is thoroughly checked out provide the owner with an operating and maintenance manual that includes design drawings and specifications, catalog sheets, sources of equipment, heat pump and air handler/fan coil installation and operating instructions, and warranty information. This information will facilitate future maintenance by persons not familiar with the system.

X. Additional Resources

Codes and Standards

- California Mechanical Code – Chapter 12 Hydronics
  https://up.codes/viewer/california/ca-mechanical-code-2016/chapter/12/hydronics#12
- Energy Code Ace – Hydronic Heating Systems
  https://up.codes/viewer/california/ca-mechanical-code-2016/chapter/12/hydronics#12
- Single Family Enhanced Air-to-Water Heat Pump Compliance Options
  https://title24stakeholders.com/measures/cycle-2022/enhanced-air-to-water-heat-pump-compliance-options/
- CSA B214:21 Installation Code for Hydronic Systems
  https://www.csagroup.org/store/product/CSA%20B214%3A21/

Reports and Articles

- Assessment of Residential Air-to-Water Heat Pumps Coupled with Thermal Energy Storage
  https://www.etcc-ca.com/reports/assessment-residential-air-water-heat-pumps-coupled-thermal-energy-storage
- Phase 2 Assessment of Residential Radiant Ceiling Panel Space Conditioning Systems
  https://www.etcc-ca.com/reports/central-valley-research-homes-phase-2-assessment-residential-radiant-ceiling-panel-space
- Green Building Advisor
  https://www.greenbuildingadvisor.com/article/air-to-water-heat-pumps
  https://www.greenbuildingadvisor.com/article/air-to-water-heat-pump-retrofit

Industry Associations and Training

- Fundamentals of Water System Design
  https://www.ashrae.org/professional-development/self-directed-learning-group-learning-texts/fundamentals-of-water-system-design
- Hydronics Industry Alliance
  https://www.iapmo.org/hiac
- Radiant Professionals Alliance
  https://www.radiantprofessionalsalliance.org/
- PG&E Energy Centers
  https://www.pge.com/en_US/small-medium-business/business-resource-center/training-and-education/energy-centers.page

Home Performance Best Practices

- Measured Home Performance
  https://www.gti.energy/measured-home-performance-a-guide-to-best-practices-for-home-energy-retrofits-in-california/