APPLICATIONS OF WATER-TO-WATER HEAT PUMPS

CLIMATEMASTER® GEOTHERMAL HEAT PUMP SYSTEMS

SMART | RESPONSIBLE | COMFORTABLE
Welcome to the ClimateMaster Applications of Water-to-Water Heat Pumps course manual.

This course is tailored for those wanting to use water-to-water heat pumps in a variety of hydronic heating and cooling applications. It will discuss how to create systems that:

1. Heat buildings
2. Cool buildings
3. Heat domestic water
4. Take advantage of time-of-use electrical rates
5. Interface water-to-water heat pumps with solar thermal collectors
6. Use multiple water to water heat pumps
7. Use heat pumps for industrial processes

The applications shown represent state-of-the-art systems for both residential and light commercial buildings.

This course assumes a basic knowledge of hydronic heating fundamentals. The ClimateMaster course: Essentials of Hydronics for Geothermal Heat Pump Professionals provides these fundamentals. This course is designed as a follow-up to the essentials of hydronics course, and will stress more advanced applications.

Given the versatility of hydronics, there is virtually no limit to the unique system piping and control designs possible. This can be both good and bad. Good in the sense that an experienced designer can modify an established system design concept to the exact requirements of a “special needs” situation. Bad from the standpoint that some inexperienced designers might create “piping aberrations” that do not perform as expected. It’s the latter that must be avoided, and doing so is a major goal of this application manual. Although not every possible piping schematic can be shown, those that are represent well-established practices to help ensure the systems you create using the information presented will perform as expected.

**Topics Covered in this manual:**

Section 1: Advantages of water-to-water heat pumps?
Section 2: Water-to-water heat pump performance fundamentals
Section 3: Hydronic heat emitter options for water-to-water heat pumps
Section 4: Heating only applications
Section 5: Chilled water cooling with water-to-water heat pumps
Section 6: Combined heating and cooling applications
Section 7: Using water-to-water heat pumps with thermal storage
Section 8: Using water-to-water heat pumps with solar collectors
Section 9: Multiple w/w heat pump systems
Section 10: DHW heating and Heat Recovery applications
Local Code Requirements:

It is impossible to present piping systems that are guaranteed to meet all applicable codes throughout the U.S. and Canada. It is the responsibility of all those using piping or electrical schematics shown in this manual to verify that such designs meet or exceed local building or mechanical codes within the jurisdiction where the system will be installed.

In some cases, local codes may require differences in design or additional safety devices from those shown in the application drawings.
Section 1: Advantages of water to water heat pumps

Heat pumps, in general, are extremely versatile devices. The unique ability of a heat pump to provide both heating and cooling over a wide range of temperatures sets them apart from devices such as boilers, which only provide heating, as well as from devices such as chillers, that only provide cooling.

This unique ability can be further enhanced by combining it with hydronic conveyance systems. The range of possible heat for such systems is very broad. Modern water-to-water heat pumps, such as shown in figure 1, are the essential component in many state-of-the-art heating and cooling systems. They can be applied in ways that are simply not possible with dedicated heating or dedicated cooling devices, or devices that rely on air to carry heat to or from the heat pump.

Figure 1-1: ClimateMaster TMW water-to-water heat pump
The key advantages of water-to-water heat pumps are as follows:

- They can be use in all types of geothermal sources (open and closed systems)
- They allow for significantly reduced distribution energy relative to forced air systems
- They allow easy (hydronic-based) zoning, at lower cost than forced air zoning
- They eliminate the need to route large central ducting in buildings
- Can be used in combination with thermal storage
- Can be used with thermal storage and off peak electrical rates
- Can be used with thermal storage and solar thermal input
- Can provide dedicated or ancillary domestic water heating
- Can be used for producing “process water” in industrial applications
- Multiple w/w heat pumps can be controlled as a staged system to better match loads
- Multiple w/w heat pumps can be stacked to save space in mechanical rooms
- Allow a hydronics professional to install system without refrigerant handling
- Can be used for loads such as pool heating, spa or hot tub heating
- Can be used in combination with solar photovoltaic systems to produce “net zero” houses
- When used with thermal storage, they be sized for the full space heating load without short cycling in cooling mode
- When used for chilled water cooling, coil frosting due to low air flow rates is eliminated
- Some water-to-water heat pumps can produce water temperatures up to 145 °F

**Distribution efficiency of water-to-water versus water-to-air heat pumps:**

Most water source heat pumps currently in use are classified as water-to-air heat pumps. In the heating mode they use a water-to-refrigerant heat exchanger as the evaporator for the refrigeration process. Their condenser is an air-cooled coil. Air flow is provided by a blower, and the conditioned air is distributed through a duct system.

Water-to-water heat pumps substitute a water-cooled condenser, and thus eliminate the blower and ducted air delivery system.
One significant advantage of using a water rather than air as the “delivery fluid” is a significant reduction in the electrical power required to operate the delivery system. This effect can be described by the concept of distribution efficiency, which is defined as follows:

\[
\text{distribution efficiency} = \frac{\text{rate of thermal energy delivery}}{\text{wattage used by delivery system}}
\]

The lower the wattage required by the delivery system (blower, circulator, etc.) relative to the rate of thermal energy (heating or cooling) delivery, the higher the distribution efficiency. The higher the distribution efficiency, all other things being equal, the lower the operating cost of the heating or cooling system.

Here’s an example: Based on published performance data, the ECM blower of a 4-ton rated water-to-air heat pump draws 3.1 amps at 230 volts (at full speed). Assuming a power factor of 0.95 for the ECM controller, this implies the blower requires 677 watts. The heat pumps rated output is 45,700 Btu/hr at 32 ºF entering source water temperature.

The distribution efficiency of this delivery system is:

\[
n_d = \frac{Q}{w_e} = \frac{45700 \text{ Btu} / \text{hr}}{677 \text{ watt}} = 67.5 \frac{\text{Btu} / \text{hr}}{\text{watt}}
\]

By comparison, using a modern ECM-based circulator, and good piping design, this rate of heat delivery could easily be accomplished using only 40 watts of distribution power.

The resulting distribution efficiency would be:

\[
n_d = \frac{Q}{w_e} = \frac{45700 \text{ Btu} / \text{hr}}{40 \text{ watt}} = 1143 \frac{\text{Btu} / \text{hr}}{\text{watt}}
\]

Thus the hydronic system delivers the same heating using only about 6% of the electrical energy used by the forced air system. This advantage is based on the thermal properties of water in comparison to those of air.
Section 2: Water-to-water heat pump performance fundamentals

All heat pumps move heat from an area of lower temperature to one at a higher temperature. The “source” from which the lower temperature heat is being taken can be just about anything. Many heat pumps extract heat from outside air. They are appropriately called “air-source” heat pumps. Geothermal heat pumps extract heat from the ground or water in contact with the ground. They are likewise referred to as ground source heat pumps.

The heat pumps discussed in this manual use a standard vapor-compression cycle of R-22 or R-410a refrigerant. As the refrigerant moves around the cycle, it changes from vapor to liquid and vice versa in a continuous process. When liquid refrigerant evaporates, it absorbs heat from its surroundings. Conversely, when a vaporous refrigerant condenses back to a liquid, it releases heat to its surroundings.

Basic refrigeration cycle within a ground source heat pump:

The basic heating mode operation of a generalized ground source heat pump operating in the heating mode is shown in figure 2-1a.

Figure 2-1a: Generalized ground source heat pump operating in heating mode
Low temperature heat from the ground is conveyed to the evaporator, usually by a flowing fluid. This heat is transferred into the refrigerant within the evaporator, which is several degrees lower in temperature. The absorbed heat causes the refrigerant within the evaporator to vaporize.

The vaporized refrigerant moves to the compressor where its pressure and temperature are greatly increased. The electrical energy needed to run the compressor is ultimately absorbed by the refrigerant, and thus adds to its total heat content.

The refrigerant exits the compressor as a hot gas, and travels on to the condenser, where it transfers heat to another “fluid” stream. For water-to-air heat pumps that fluid is air. For water-to-water heat pumps that fluid is water. As the refrigerant releases heat it condenses from a vapor to a liquid, and its temperature also decreases. However, the pressure of the liquid refrigerant is still relatively high.

The high pressure liquid refrigerant then passes through the thermal expansion valve (TXV). The pressure drop that occurs as the refrigerant passes through the TXV causes it temperature to drop dramatically. As the refrigerant enters the evaporator, it is in the same pressure / temperature state as where this description began, and is ready to repeat the process.

This refrigeration cycle also takes place when the heat pump is in the cooling mode as seen in figure 2-1b. The difference is that heat is being absorbed from the building and dissipated to another fluid stream such as that flowing through an earth loop.

Figure 2-1b: Generalized ground source heat pump operating in cooling mode
Water-to-water heat pumps:

The discussion will now turn, more specifically, to water-to-water heat pumps. The basic components used in a non-reversible water-to-water heat pump are shown in figure 2-2.

![Diagram of refrigerant flow in a non-reversible water-to-water heat pump](image)

**Figure 2-2: Refrigerant flow in a non-reversible water-to-water heat pump**

Let’s again follow the refrigerant cycle, beginning in the evaporator.

Refrigerant enters the evaporator as a low-temperature, low-pressure liquid. It passes across the surface of copper or steel tubing through which water or a mixture of water and antifreeze is flowing. Because the liquid refrigerant is several degrees colder than the water, heat moves from the water through the copper or steel tubing wall, and is absorbed by the refrigerant. As heat is absorbed, the cold liquid refrigerant vaporizes or evaporates. The vapor collects at the top of the evaporator (shown as bubbles in figure 2-2).

The cool refrigerant vapor then passes to the compressor. Here the vapor is compressed, and its temperature immediately increases. The hot gas line leaving the compressor can be quite hot (130 to 170°F). The gaseous refrigerant now contains the
energy it absorbed in the evaporator PLUS most of the energy that was supplied by electricity to operate the compressor.

The hot gas then flows to the condenser. Here it passes across another coil of copper tubing carrying water that flows through a hydronic distribution system. Because the hot refrigerant gas is warmer than the water, heat moves from the gas to the water. This causes the refrigerant gas to condense back to a liquid, but still remain at a relative high pressure.

Finally, the liquid refrigerant goes from the condenser to the thermal expansion valve (TXV). Here its pressure is reduced, and its temperature immediately drops. The refrigerant is now back to the same condition at which we began examining the cycle, and it is ready to enter the evaporator to begin the same process again.

The materials and shapes used to construct the evaporator and condenser of a water-to-water heat pump vary from one manufacturer to another. However, the goal is always the same: To move heat from the low-temperature “source” to the higher temperature “sink” using as little electrical energy as possible to operate the compressor.

**Reversible Water-To-Water Heat Pumps:**

As with air-source heat pumps, a reversing valve can be added to a water-to-water heat pump. This allows it to provide either heated water or chilled water. The latter can be used for building cooling or for other processes requiring chilled water. The basic internal design of a reversible water-to-water heat pump (in the heating mode) is shown in figure 2-3.

![Figure 2-3: A reversible water-to-water heat pump (operating in heating mode).](image)
When the reversing valve is activated by a 24VAC signal, refrigerant flow is reversed through the evaporator and condenser. The heat absorbed from the building’s hydronic distribution system is added to the heat generated by the compressor. The combined heat is then transferred to the water stream flowing through the condenser. In a ground source system, this heat is then carried to and dissipated into the earth or directly to ground water. The flow of refrigerant in a reversible water-to-water heat pump operating in the cooling mode is shown in figure 2-4.

![Diagram of a reversible water-to-water heat pump](image)

**Figure 2-4: A reversible water-to-water heat pump (operating in cooling mode).**

**Optional Domestic Heating Mode:**

Some water-to-water heat pumps are available with an optional desuperheater heat exchanger, which is typically used to heat domestic water.

The desuperheater is a refrigerant to water heat exchanger that receives hot refrigerant gas directly from the compressor discharge as shown in figure 2-5.
Figure 2-5: Water-to-water heat pump equipped with desuperheater heat exchanger for domestic water heating.

The hot refrigerant leaving the compressor has a temperature that is several degrees higher than its saturation temperature (e.g. The temperature at which the refrigerant gas is about to condense). The heat that causes this temperature elevation is called superheat, and it must be removed from the refrigerant before it can begin condensing. In heat pumps without a desuperheater, this heat is released to the fluid stream flowing through the condenser. However, when a desuperheater heat exchanger is present, this superheat is removed before the refrigerant gas reaches the condenser.

Water-to-water heat pumps equipped with superheaters are also equipped with a small, low power (1/150 hp) internal bronze circulator. When operating, this circulator creates flow of domestic water between a storage tank and the desuperheater. This water flow is what absorbs the superheat energy from the refrigerant, and ultimately moves it to the storage tank. A typical setup for domestic water heating is shown in figure 2-6.
If the desuperheater circulator is off, the hot refrigerant gas simply passes through the desuperheater and thus carries more thermal energy on to the condenser.

It is important to understand that any thermal energy removed from the refrigerant gas by the desuperheater is unavailable for the heating load served by the condenser. When the condenser of the water-to-water heat pump is serving a space heating load, the heat removed by the desuperheater is used to heat domestic water and thus not available to heat the building. However, when the heat pump is operating in the cooling mode, any heat removed from the refrigerant by the desuperheater is heat that otherwise would be dissipated to the ground. Thus, it is correct to state that this heat is “free” since it would otherwise have no further value within the building.
Dedicated Domestic Hot water Mode:

The ClimateMaster THW heat pump, shown in figure 2-7, includes a dedicated domestic hot water mode. Unlike other water-to-water heat pumps that are equipped with desuperheaters for domestic water heating, the dedicated domestic water heating mode of the THW is fully-condensing, and can provide approximately three tons (36,000 Btu/hr) of domestic water heating capacity. The THW includes two degrees of internal separation between the refrigerant and the potable water, as well as a bronze internal potable water circulator. This mode can provide up to 145°F domestic water.

Figure 2-7: Internal view of ClimateMaster THW water-to-water heat pump.
Water-to-Water Heat Pump Performance (Heating Mode):

In hydronic heating system applications, there are two performance characteristics that are particularly important:

• Heating Capacity
• Coefficient of Performance

These performance indices both vary based on the operating conditions of the heat pump. Both are affected by the distribution system the heat pump is coupled to.

The heating capacity is very dependent on the temperature of the fluid entering the evaporator, and the temperature of the water returning to the condenser from the hydronic distribution system. A graph showing the variation in capacity is shown in figure 2-8.

![Graph showing heating capacity of water-to-water heat pump vs. entering source water temperature.](image)

Figure 2-8: Heating capacity of water-to-water heat pump vs. entering source water temperature.

The flow rate through the evaporator and condenser also affect the heat pump’s heating capacity. Figure 2-9 shows this effect for a ClimateMaster TMW036 unit operating with a source water flow rate of 9 gpm and 5 gpm.
Notice that the heating capacity decreases slightly as the flow rate through the evaporator decreases. This is also true for flow rate through the condenser. Lower flow rates reduce convection heat transfer on the water side of these heat exchangers (e.g., the evaporator and condenser). This in turn reduces the rate of heat transfer through them, and hence lowers their heating capacity.

**Coefficient of Performance:**

The thermal performance of many hydronic heat sources is expressed as an “efficiency,” which indicates the ratio of a desired output divided by the necessary input.

\[
\text{Efficiency} = \frac{\text{Desired output}}{\text{Necessary input}}
\]

When the units in the top and bottom of the fraction are the same, the efficiency is simply a decimal percentage. For example: Consider a boiler in constant operation that consumes 0.9 therms of natural gas in an hour. During that hour, the boiler delivers 78,000 Btu of heat. Its thermal efficiency could be calculated as:

\[
\text{Efficiency} = \frac{\text{Desired output}}{\text{Necessary input}} = \frac{78,000 \text{Btu/hr}}{(0.9) \times 100,000 \text{Btu/hr}} = 0.866 = 86.6\% 
\]
A similar definition applies to the efficiency of a heat pump (e.g., the ratio of the desired output to the necessary input). The desired output is the heating capacity. The necessary input is the electrical power needed to operate the heat pump. This ratio is called the coefficient of performance of the heat pump, and is abbreviated as COP. Since the electrical power to operate the heat pump is usually expressed as wattage, the convenient form of the COP formula is:

\[
\text{COP} = \frac{\text{heating capacity (Btu/hr)}}{(\text{input wattage}) \times 3.413}
\]

For example: Assume the input power to operate a heat pump was 2,000 watts. The heat pump’s heating capacity under this condition was 24,000 Btu/hr. Its COP would be:

\[
\text{COP} = \frac{24,000 \text{ Btu/hr}}{(2,000 \text{ watt}) \times 3.413} = 3.52
\]

Notice that the units of watt and Btu/hr both cancel out in this formula. This means the COP is just a number with no units. The best way to think of COP is the number of units of heat output the heat pump provides per unit of electrical input energy. If the COP of a heat pump is 3.5, it provides 3.5 units of heat output per unit of electrical energy input.

One could also think of COP as the number of times “better” the heat pump is at producing heat compared to an electrical resistance heating device. The COP of an electrical resistance heating device will always be 1.00.

Another way to think of COP is to multiply it by 100 and use that number as a comparison to the efficiency of electric resistance heat. For example, if electrical resistance heat is 100% efficient, then by comparison, a heat pump with a COP of 3.5 would be 350% efficient.

The quantities that go into making up the COP of a heat pump are shown in figure 2-10.
The heating capacity or COP of a water-to-water heat pump is very dependent on the operating conditions (e.g., the entering source water temperature and its flow rates, as well as the entering load water temperature and its flow rate). A graph showing how the COP of a ClimateMaster TMW036 heat pump varies as a function of entering source water temperature and entering load water temperature is shown in figure 2-11.
This graph shows that the heat pump’s COP improves with warmer source water temperatures as well as cooler load water temperatures. This means it’s best to keep the water temperature from the ground source as high as possible, while at the same time keeping the required operating temperature of the hydronic distribution system as low as possible. High source and low load operating temperatures also improve heating capacity. These are both key issues when interfacing a water-to-water heat pump with a hydronic distribution system.

**Cooling Performance:**

A unique benefit of many water-to-water heat pumps is that they are reversible, and thus able to operate as chillers. The cold water they produce can be used for cooling and dehumidifying both residential and commercial buildings.

Designing a chilled-water cooling system involves knowledge of how choices in the hydronic distribution system will affect operation of the heat pump. To that end, we will look at the cooling performance of water-to-water heat pumps in a manner similar to that just discussed for heating performance.

The cooling performance of a water-to-water heat pump can be categorized as follows:

- Cooling Capacity
- Energy Efficiency Ratio (EER)
Cooling capacity represents the total cooling effect (sensible cooling and latent cooling) that a given heat pump can produce while operating at specific conditions. Unlike a water-to-air heat pump, which has separate ratings for sensible and latent cooling capacity, a water-to-water heat pump has a single total cooling capacity rating. This rating is affected by the temperature of the fluid streams passing through the evaporator and condenser. To a lesser extent, it’s also affected by the flow rates of these two fluid streams.

The cooling capacity of a ClimateMaster TMW036 water-to-water heat pump is shown graphically in figure 2-12.

Figure 2-12: Cooling capacity versus entering load water temperature.

As the temperature of the entering load water goes up, so does the cooling capacity. Keep in mind that lower entering load water temperature will produce better sensible and latent cooling effect. It can also be seen that increasing temperature from the earth loop decreases the cooling capacity of the heat pump.

The common way to express the cooling efficiency of a water-to-water heat pump is an index called EER (Energy Efficiency Ratio), which is defined as follows:

\[
EER = \frac{Q}{w_e} = \frac{\text{cooling capacity (Btu/hr)}}{\text{electrical input wattage}}
\]
Where:

EER = Energy Efficiency Ratio  
Qc = cooling capacity (Btu/hr)  
We = electrical input wattage to heat pump (watts)

The higher the EER of a heat pump, the lower the amount of electrical power being used to produce a given rate of cooling.

Like COP, the EER of a water-to-water heat pump is a function of the source and load water temperature, as well as the source and load water flow rate. This variation is shown in figure 2-13.

![Figure 2-13: EER (Energy Efficiency Ratio) versus entering load water temperature.](image)

This plot shows that EER increases as the temperature of the entering load water increases. Keep in mind that lower entering load water temperatures are better for cooling capacity.

It can also be seen that the cooler the source water (such as supplied from an earth loop heat exchanger), the higher the EER. Thus, cooling performance will generally be better at the beginning of a cooling season when earth temperatures are still relatively low, compared to late summer when the earth has warmed.

As is true with heating, design decisions that reduce the difference between the source water and load water temperatures will improve the cooling capacity and efficiency (as measured by EER) of the heat pump.
Water-to-water heat pumps are often coupled with an air handler to provide cooling. The power of the air handler must also be considered when determining overall system efficiency.

The latter sections of this manual will show you how to combine water-to-water heat pumps with a variety of other hydronic heating hardware to produce systems for both heating and cooling.
Section 3: Hydronic heat emitter options for water-to-water heat pumps

As discussed in section 2, the heating efficiency (e.g., COP) and heating capacity of a water-to-water GSHP system is very dependent on the water temperature at which the distribution system operates. The lower this temperature, the better the GSHP performs. This implies that low temperature hydronic heat emitters are essential if the system is to perform well. This section discusses several heat emitter systems that can perform well when supplied by a GSHP.

What NOT to Use:

Fin-tube baseboard is one of the most common hydronic heat emitters in the North American market. This hydronic heat emitter was designed around boilers in an era when water temperatures of 180°F or higher were commonly used, and thermal efficiency was not of paramount importance. Such water temperatures are much higher than can be attained with current-generation ground source heat pump systems.

Fin-tube baseboard releases less heat at lower water temperatures. However, the heat output at 120°F water temperature is only about 28% of that at 180°F water temperature. Thus, about 3.5 times as much linear footage of baseboard would be required at 120°F water temperature to produce equivalent heat output of baseboard operated at 180°F water temperature. This is clearly impractical from both a space and aesthetic standpoint. Thus, the combination of fin-tube baseboard and a GSHP is NOT recommended.

![Figure 3-1: Fin-tube baseboard typically requires higher water temperatures than can be generated with a geothermal heat pump.](image)
A similar argument can be made for “plateless staple-up” radiant floor heating (see figure 3-2). Such an installation is very limited in its heat output, especially at the lower water temperatures supplied by a geothermal heat pump.

Figure 3-2: Never install floor-heating tubing like this! The required operating water temperature would be very high.

A suggested guideline is that space-heating distribution systems used with geothermal heat pumps should provide design heating load output using supply water temperatures no higher than 120ºF.

Distribution systems that supply each heat emitter using parallel piping branches rather than series configurations are also preferred because they provide the same supply water temperature to each heat emitter.

Examples of space-heating systems that allow the GSHP to provide good performance include:

- Heated floor slabs with low-resistance coverings
- Heated thin-slabs over framed floors with low-resistance floor coverings
- Heated floors using aluminum heat transfer plates or layers for lateral heat conduction.
- Radiant wall and ceiling panels
- Generously sized panel radiator systems with parallel piping

Each of these systems will be discussed separately in this section. A construction detail for the site built radiant panels will be shown, and key issues related to the system summarized by listing strengths and limitations, as well as things that should always be done, and things that should never be done.
Other heat emitters options may also be possible provided they can operate at relatively low supply water temperatures.

**Slab-on-grade Radiant Floor:**

One of the most common types of radiant panel is a heated floor slab, as shown in figure 3-3. This type of radiant panel has one of the lowest supply water temperature requirements of any hydronic heat emitter, and thus will perform well with a ground source water-to-water heat pump.

![Cross-section of a heating slab-on-grade floor.](image)

To keep the supply water temperature low, it’s important to:

a. Keep tube spacing relatively close.

b. Keep the thermal resistance of the finish floor as low as possible.

The graph in figure 3-4 shows upward heat output from a heated slab based on tube spacing of 6 inches and 12 inches, and for finish floor resistances ranging from 0 to 2.0°F•hr•ft²/Btu. The steeper the line, the better the distribution system is suited for use with a GSHP.
Figure 3-4: The effect of finish floor resistance on upward heat output of a heated slab floor.

Achieving an upward heat output of 25 Btu/hr/ft² from a slab with no covering (e.g., Rff = 0) and 6” tube spacing requires the “driving ΔT” (e.g., the difference between average water temperature in tubing and room air temperature) to be about 22ºF. Thus, in a room maintained at 70ºF, the average water temperature in the circuit needs to be 92ºF. The supply water temperature to the circuit would likely be in the range of 102ºF. This is a relatively low supply water temperature, and should allow the GSHP to operate at good efficiency.

However, if this same heat output is required from a slab with 12” tube spacing and a finish floor resistance of 1.0ºF•hr•ft²/Btu. The driving ΔT must be 53ºF. The average circuit water temperature required to maintain a room temperature of 70ºF would be 123ºF, and the supply temperature likely in the range of 133ºF. This supply temperature is higher than recommended for most R-22-based heat pumps, although some R-410A-based heat pumps, such as the ClimateMaster THW series, are capable of reaching this supply temperature.

The following guidelines are suggested in applications where a heated floor slab will be used to deliver heat derived from a solar collector array:

• Tube spacing within the slab should never exceed 12 inches.

• Slab should have a minimum of R-10 insulation on its underside.
• Tubing should be placed at approximately 1/2 the slab depth below the surface, as shown in figure 3-5. Leaving the tube at the bottom of the slab can increase the required supply water temperature several degrees Fahrenheit. This will decrease the heating capacity and COP of the heat pump.

• Bare, painted or stained slab surfaces are ideal because the finish floor resistance is essentially zero.

• Other floor finishes should have a Total R-value of 1.0 or less.

Figure 3-5: PEX-AL-PEX tubing and reinforcing mesh being lifted as concrete is placed for a heated slab-on-grade floor.

Summary of heated slab-on-grade floors:

• Typical water supply temperature at design load = 95° to 120°F

Strengths:
  • Most economical installation (slab is already part of building)
  • Operates on low water temperatures (good match to GSHP)
  • Very durable
  • High thermal storage responds well to cold air influx

Limitations:
  • Slow thermal response (best when loads are slow to change)
  • Quality control dependent on masons
Always…
- Verify proper preparation of subgrade
- Insulate edge and underside of slab
- Lift welded wire reinforcing with tubing during pour
- Use proper detailing at control joints
- Pressure-test circuits prior to placing concrete
- Make tubing layout drawing prior to placing tubing

Never…
- Drive power buggies or trucks over tubing
- Pressure-test with water
- Cover with flooring having total R-value over 2.0°F hr/ft²/Btu

Thin-slab (Concrete) Radiant Floors:

Another method of constructing a heated floor is called a “thin-slab.” It is created by placing a thin (1.5” thick) layer of concrete over tubing that has been fastened to a wooden subfloor as shown in figure 3-6.

Figure 3-6: Cross-section of a concrete thin-slab heated floor.

Figure 3-7 shows tubing installed over a layer of 6-mil polyethylene sheeting. The latter serves to prevent bonding between the underside of the concrete and the wooden subfloor. This, in turn, helps reduce tensile stress in the concrete as the slab cures. The concrete will be placed to a depth of 1.5 inches above the subfloor. Slab thickness is controlled by screeded level with the top of the 2x4 and 2x6 wall plates.
Figure 3-7: Tubing being placed over polyethylene sheeting awaiting placement of concrete thin-slab.

Summary of thin-slab (concrete) heated floors:

Typical water supply temperature at design load = 95° to 120°F

Strengths:
- Usually lower installed cost relative to poured gypsum thin-slab
- Operate on low water temperatures (good match to GSHP)
- Very durable, waterproof
- Medium thermal storage tends to smooth heat delivery

Limitations:
- Slower thermal response (best when loads are slow to change)
- Adds about 18 pounds/square foot to floor loading @ 1.5” thickness

Always…
- Verify load carrying ability of floor framing
- Account for added 1.5 inches in floor height
- Install control joints and release oil on adjacent framing
- Install polyethylene bond breaker layer between subfloor and slab
- Pressure-test circuits prior to placing concrete
- Make tubing layout drawing prior to placing tubing
- Install R-11 to R-30 underside insulation
Never...

- Allow concrete to freeze prior to curing
- Pressure-test with water
- Place tubing closer than 9 inches to toilet flanges
- Cover with flooring having total R-value over 2.0°F hr/ft²/Btu
- Use asphalt-saturated roofing felt for bond breaker layer
- Exceed 12” tube spacing

Thin-slab (Poured Gypsum Underlayment) Radiant Floors:

Another type of thin-slab is created using poured gypsum underlayment rather than concrete. A cross-section of this floor is shown in figure 3-8.

![Cross-section of a poured gypsum underlayment heated floor.](image)

Figure 3-8: Cross-section of a poured gypsum underlayment heated floor.

As in the case of concrete, the slab thickness is typically 1.5 inches. The difference is that the poured gypsum material has a much greater flow characteristic than concrete. It is pumped into the building through a hose and is largely self-leveling as it is placed on the subfloor (see figure 3-9). No polyethylene sheet is used to break the bond between the poured underlayment and the subfloor.
3-9: Poured gypsum underlayment being placed over hydronic tubing fastened to wood subfloor.

**Summary of thin-slab (poured gypsum underlayment) heated floor:**

• Typical water supply temperature at design load = 95° to 120°F

**Strengths:**
  • Faster installation than concrete thin-slab
  • Operates on low water temperatures (good match to GSHP)
  • Excellent air sealing at wall/floor intersection
  • Medium thermal storage tends to smooth heat delivery
  • No control joints required

**Limitations:**
  • Slower thermal response (best when loads are slow to change)
  • Adds about 14.5 pounds/square foot to floor loading @ 1.5” thickness
  • Not waterproof

**Always…**
  • Verify load-carrying ability of floor framing
  • Account for added 1.5 inches in floor height
  • Pressure-test circuits prior to placing gypsum underlayment
  • Make tubing layout drawing prior to placing tubing
  • Install R-11 to R-30 underside insulation
  • Use proper surface preparations prior to finish flooring
Never…
- Allow gypsum to freeze prior to curing
- Pressure-test with water
- Place tubing closer than 9 inches to toilet flanges
- Cover with flooring having total R-value over 2.0°F hr/ft²/Btu
- Exceed 12” tube spacing
- Install in locations that could be flooded

**Above Floor Tube & Plate Radiant Floors:**

One final radiant floor panel that would be compatible with geothermal heat pumps (under specific circumstances) is shown in figure 3-10. This system is known as an above floor tube and plate system. Rather than concrete or poured gypsum underlayment, this system uses thin aluminum plates to conduct heat away from the tubing and spread it out across the floor surface.

![Figure 3-10: Cross-section of an above floor tube and plate system.](image)

An example of an above floor tube and plate system being covered with nail-down hardwood flooring is shown in figure 3-11.
Figure 3-11: Hardwood flooring being nailed down over an above floor tube and plate radiant panel.

It’s important to realize that the supply water temperature to this type of system is often higher than that of slab-type systems. When used with a GSHP, the lower end of this temperature range will provide the best efficiency.

• Typical water supply temperature at design load = 120° to 145°F

Strengths:
- Adds very little weight to floor
- Operates on medium water temperatures (some potential for GSHP)
- Minimizes resistance between plates and top of floor
- Relatively low thermal mass for fast response
- Excellent for use with nailed-down wood flooring
- Doesn’t require tubing to run parallel with floor joists

Limitations:
- Potential to cause expansion sounds if not properly installed
- Requires several “passes” over floor during installation; labor intensive
- Requires considerable amount of wood fabrication

Always…
- Staple only one side of plate to sleeper — allow for expansion
- Account for added 3/4” in floor height
- Pressure-test circuits prior to covering
- Make tubing layout drawing prior to placing tubing
- Install R-11 to R-30 underside insulation
Never...
- Place in an area where nails might penetrate tubing
- Pressure-test with water
- Place tubing closer than 9 inches to toilet flanges
- Cover with flooring having total R-value over 2.0°F hr/ft²/Btu
- Exceed 12” tube spacing

Floor Warming:

In some systems, a heated floor may only provide part of the total heating load. This may be due to high loads (those higher than 40 Btu/hr/ft²). In such cases, some other type of heat emitter, hydronic or otherwise, is used to supplement the heat output of the floor so that the space remains comfortable.

Floor warming is also used in combination with hydronic air handlers. The heated floor may operate with surface temperatures in the range of 73°F to 80°F to cover the “base load” of the space. The air handlers then add any additional heat necessary to maintain room temperature.

This approach is well suited to situations where unpredictable internal heat gains from sunlight, occupants, equipment or other sources are likely. It allows the system to adapt to these gains rapidly, and thus minimizes the potential temperature overshoot that could occur if a high-mass heated floor was the only heat emitter present.

Floor warming also allows the heat pump to operate at relatively low supply water temperatures, and thus at high COPs.

Radiant Wall Panels:

Radiant panels can be integrated into walls and ceilings as well as floors. Two configurations that would be well suited for GSHPs both use the same aluminum plate system just described. An example of a radiant wall constructed using aluminum plates is shown in figure 3-12 and figure 3-13.
The radiant wall design shown has very low thermal mass compared to the floor-heating panels previously described. This makes it very responsive to changes in internal heat.
gains or thermostat settings. Such a characteristic is very desirable in buildings with significant solar heat gain, or situations where temperature setback schedules are used.

Radiant walls can also be incorporated in areas such as stair walls (see figure 3-14), or walls under a kitchen island.

Figure 3-14: The wall around these stairs is a radiant panel with embedded tubing and aluminum plates.

The heat output of a radiant wall constructed as shown can be estimated using the following formula.

\[ q = 0.8 \times (T_{\text{water}} - T_{\text{room}}) \]

Where:

- \( Q \) = heat output of wall (Btu/hr/ft\(^2\))
- \( T_{\text{water}} \) = average water temperature in panel (°F)
- \( T_{\text{room}} \) = room air temperature (°F)
Radiant Ceiling Panels:

The same type of construction shown for radiant walls can also be incorporated into ceilings, as shown in figure 3-15 and 3-16. Like the radiant wall design, this radiant ceiling panel can respond very quickly. Radiant ceilings also have the advantage of not being blocked by furniture or covered with other materials that reduce heat transfer.

[insert figure 3-15]

Figure 3-15: Cross-section of a low thermal mass radiant ceiling panel using aluminum plates.
The heat output of a radiant ceiling constructed as shown can be estimated using the following formula.

\[ q = 0.71 \times (T_{water} - T_{room}) \]

Where:

- \( q \) = heat output of wall (Btu/hr/ft\(^2\))
- \( T_{water} \) = average water temperature in panel (\(^\circ\)F)
- \( T_{room} \) = room air temperature (\(^\circ\)F)

**Panel Radiators:**

Extensively used in European systems, panel radiators are becoming increasingly popular in North America. Base-model panel radiators are built of pressed steel plates, and come in a wide variety of shapes and sizes. With proper sizing (for low supply water temperatures), they can be used in combination with water-to-water GSHPs.

An example of a typical panel installation is shown in figure 3-17.
The heat output of a panel radiator is very dependent on its size as well as its supply water temperature. The table in figure 3-18 lists the “reference” heat output of several common-size panels. This output is based on 180ºF average water temperature in the panel, and 68ºF room temperature. The water temperature is much higher than what can be attained with a typical geothermal heat pump. However, the reference heat output can be corrected for differences in average water temperature, as well as different room air temperatures. Use the curve or formula shown in figure 3-19 to determine a multiplier for the reference heat output to correct it for different operating conditions.
Figure 3-18: Reference heat output ratings for panel radiators.

Figure 3-19: Correction factor for adjusting the reference heat output to other operating conditions.
For example: Figure 3-18 indicates that a panel with a single water plate, measuring 24 inches high and 72 inches long, has a heat output of 8,447 Btu/hr based on the reference conditions of 180 ºF average water temperature and 68ºF room air temperature. Using the formula in figure 3-19, the correction factor with an average panel water temperature of 110ºF and room temperature of 68ºF is:

\[
CF = 0.001882 (110 - 68)^{1.33} = 0.271
\]

The estimated heat output at the lower water temperature is thus:

\[
Output = (0.271) \times 8447 = 2289 Btu / hr
\]

This demonstrates that systems limiting the supply water temperature to 120ºF to retain good performance of the GSHP often require substantially larger panel radiators compared to systems with conventional heat sources that often supply much higher water temperatures.

**Summary of heat emitter operating conditions:**

Figure 3-20 summarizes the practical ranges of supply water temperature for each of the heat emitters discussed in this section. Sizing for the lowest possible supply water temperature will always enhance the performance of the water-to-water heat pump.
Suggested application range of hydronic heat emitters
(based on supply water temperature at design load)

Figure 3-20: Practical ranges of supply water temperature for various heat emitters.
Section 4: Heating only applications

This section presents several schematics for heating only applications of single water-to-water heat pumps. Each system schematic is numbered and summarized. The schematics show the major components necessary in the system, but may not include every component required for the system to meet a specific mechanical code, or installation condition.

Single zone radiant floor heating (Figure 4-1):

This system uses a single, non-reversible water-to-water heat pump to supply a single radiant panel manifold station. There is no need for a buffer tank since the entire distribution system operates as a single zone. The heat pump, earth loop circulator and distribution circulator would all operate together. *THIS PIPING IS ONLY APPROPRIATE FOR SINGLE ZONE SYSTEMS.* It is also critical that the distribution system as a whole is sized to allow the heat pump to operate with supply water temperatures that allow for good performance. A maximum supply water temperature of 120 °F at design load conditions is suggested.

Figure 4-1: Single zone, heating-only application with low temperature radiant panel circuits serving as the heat emitter.
Single zone system with desuperheater for domestic water preheating (Figure 4-2):

The water-to-water heat pump in figure 4-2 is equipped with a desuperheater. Heat is extracted directly from the hot compressor discharge gas and used to preheat domestic water being circulated from the DHW storage tank. The desuperheater function operates whenever the heat pump is running. The small circulator used to circulate domestic water between the heat pump and tank must be rated for open loop systems. Such circulators have bronze, stainless steel, or polymer volutes and impellers. This circulator is often built into water-to-water heat pumps equipped with a desuperheater. THIS PIPING IS ONLY APPROPRIATE FOR SINGLE ZONE SYSTEMS.

Figure 4-2: Single zone space heating plus DHW preheating using a desuperheater. Buffer tank is not required.
Multi-zone radiant panel heating using zone valves (Figure 4-3):

This system addresses one of the major benefits of hydronics: Zoning. It uses a high-efficiency variable-speed circulator to control flow through zone circuits that are in turn controlled by zone valves. The water-to-water heat pump is operated by an outdoor reset controller, which maintains the target temperature of the buffer tank based on the current outdoor temperature. The reset controller is adjusted based on the supply temperature requirement of the radiant panel zones. DHW preheating is provided by a desuperheater in the heat pump, and boosted, if necessary, by the heating element in the water heater. *All ClimateMaster THW series water-to-water heat pumps include this outdoor reset capability.*

![Figure 4-3: A multi-zone system supplies DHW preheating and zoned space heating via zone valves and a variable-speed circulator.](image-url)
Homerun distribution system supplying panel radiators (Figure 4-4):

The system shown in figure 4-4 is similar to that shown in figure 4-3. The difference is in the distribution system on the right side of the buffer tank. The system in figure 4-4 uses a “homerun” distribution system, which consists of a manifold station and individual supply/return piping to each panel radiator. This piping is flexible ½-inch PEX or PEX-AL-PEX tubing. Such tubing is easy to route through framing cavities in either new construction or retrofit applications. The heat emitters are panel radiators with individual thermostatic radiator valves that allow room-by-room temperature control. To keep the GSHP within its normal operating range, these radiators have been sized to provide design heat output at a supply water temperature of 120ºF. If a ClimateMaster THW series heat pump is used, the supply water temperature can be as high as 145ºF. Increasing the supply water temperature will decrease the size of the panel radiator needed for a given heat output. The variable-speed, pressure-regulated circulator continually monitors the differential pressure between the supply and return side of the distribution system, and adjusts its speed as necessary to maintain a set differential pressure.

Figure 4-4: Multi-zone system supplies DHW preheating and zoned space heating using a homerun distribution system to supply panel radiators. Heat output form each radiator is regulated by a non-electric thermostat valve.
Multiple water temperature distribution system (Figure 4-5):

This system supplies two space heating loads that require different water temperatures. The outdoor reset controller maintains the buffer tank close to the target temperature required by the higher temperature load. Water flows directly from the buffer tank to this load (no mixing). The lower temperature load is supplied through a 3-way motorized mixing valve, which blends in some cooler return water to achieve the lower supply temperature. The heat pump operates to maintain the temperature of the buffer tank within a range that is suitable for the higher temperature load. This temperature range could be based on a set point or outdoor reset control. Similarly, the 3-way mixing valve operates to maintain the supply temperature needed by the lower temperature load. Again, this could be based on a set point or outdoor reset control.

Figure 4-5: A two-temperature distribution system. The mixing valve is used to create a lower supply water temperature.

Sizing Buffer Tanks for zoned systems:

Buffer tanks provide the thermal mass that allows the rate of heat generation by the heat source to be significantly different from the rate of heat dissipation by the
distribution system. They are an essential component in any hydronic system that uses a low thermal mass on/off heat source in combination with an extensively zones distribution system.

The required volume of a buffer tank depends on the rates of heat input and release, as well as the allowed temperature rise of the tank from when the heat source is turned on, to when it is turned off. The greater the tank’s volume, and the wider the operating temperature differential, the longer the heat source cycle length.

Formula 4-1 can be used to calculate the volume necessary when given a specified minimum heat source on-time, tank operating differential and rate of heat transfer:

**Formula 4-1**

\[ v = \frac{t \times Q_{\text{heat source}}}{500 \times (\Delta T)} \]

Where:

\( v \) = required volume of the buffer tank (gallons)
\( t \) = desired duration of the heat source’s “on cycle” (minutes)
\( Q_{\text{heat source}} \) = heat output rate of the heat source (Btu/hr)
\( q_{\text{load}} \) = rate of heat extraction from the tank (Btu/hr)
\( \Delta T \) = temperature rise of the tank from when the heat source is turned on to when it is turned off (°F)

For example, assume it’s desired that a heat pump operates with a minimum compressor on-cycle duration of 10 minutes. The heat pump, when on, supplies 60,000 Btu/hr. The compressor turns on when the buffer tank temperature drops to 100°F, and off when the tank reaches 120°F. What is the necessary tank buffer tank volume to accomplish this?

Solution: Substituting the numbers into Formula 4-1 yields:

\[ v = \frac{10 \times 60,000}{500 \times (120 - 100)} = 60 \text{ gallons} \]

If a tank larger than the minimum required volume is used, the on-cycle length could be increased, or the temperature differential through which the tank cycles could be reduced.

The wider the temperature differential, and the greater the volume of the tank, the longer the heat source on-cycle will be.
Figure 4-6 shows an example of a commercially available buffer tank. This product is currently available in 30- and 80-gallon sizes. This tank has 2 inches of polyurethane insulation, 4 large connection ports, an air vent at the top, and a drain valve at the bottom.

When placed between the heat pump and loads, a buffer tank of this design also provides hydraulic separation between the heat pump condenser circulator and the circulator(s) used in the distribution system. This is especially beneficial when the distribution system uses a variable-speed circulator.

**Combined Buffer/DHW Tanks:**

Another way to achieve the benefits of a buffering thermal mass is to use an indirect water heater as a buffer tank. One possible configuration is shown in figure 4-7.
Figure 4-7: The buffer tank also serves to heat domestic water.
Section 5: Chilled water cooling with water-to-water heat pumps

Just as there are heating-only applications for water-to-water heat pumps, there are also cooling-only applications. Such systems use a non-reversible heat pump with the condenser connected to the heat dissipating media (usually an earth loop), and the evaporator connected the chilled water distribution system or buffer tank.

Some advantages of chilled water cooling include:

- Allows multiple smaller air handlers to be located for easy zoning cooling
- Cannot frost air handler coil due to lower air flow rates - as can happen with DX coils
- When a buffer tank is used in the cooling mode, the heat pump can be sized for full design load heating without being oversized for cooling
- Can be installed without refrigerant handling
- Allows option for “off-peak” chilling in combination with thermal storage
- Less refrigerant content than a mini-split system
- Higher EER than air-cooled chillers - especially in northern climates
- Eliminates visible outdoor equipment
- When used with “passive” terminal units such as chilled beams and radiant panels, chilled water cooling significantly reduces the distribution energy required for sensible cooling.
- Passive terminal units create lower velocity natural convection air currents that reduce draft and noise
- May allow for significantly reduced duct sizes relative to all-air delivery systems. This, in turn, may allow for reduced building (or story) heights.
- Under some circumstances, chilled water cooling is possible using ground water or lake water without heat pump assist - primarily in Northern climates.

One disadvantage of chilled water cooling is that air handlers and piping placed in unconditioned spaces such as attics must be protected against freezing.

Many of the same principles and hydronic details that apply to heating only applications also apply to cooling-only applications.

One critical difference between heating and cooling with water, it that all piping and piping components that hold or convey chilled water must be insulated, and that insulation vapor sealed, to prevent condensation.
Terminal units for chilled water cooling:

There are now many types of terminal units available in North America for providing cooled and de-humidified air to spaces using chilled water. The range of devices includes:

- Concealed air handlers with standard blowers
- Concealed air handlers with high static pressure blower ("mini-duct" systems)
- Ceiling mounted air handlers with bottom side supply and return air
- Console air handlers
- Wall-mounted air handlers
- Cooled ceilings and floors
- Chilled beams

Examples of some of these devices are shown in the following figures:

Figure 5-1: Concealed chilled-water air handler with standard tangential blower designed to be mounted above a ceiling, and connected to standard ducting. Product by Aermec.
Figure 5-2: Concealed chilled-water air handler with high static pressure blower designed to be mounted above a ceiling, and connected to mini-ducting (1.5” to 2” diameter flexible ducting). Product by Mestek.

Figure 5-3: Ceiling mounted air handler with bottom side supply and return air. Product by Aermec.
All terminal units shown in figure 5-1 through 5-5 contain internal drip panels that catch condensation dripping from the chilled water coil. The accumulated condensate exits the drip pans through a piping connection that leads to a disposal location (either outside or into a building drainage system). In the latter case, the drainage piping must contain a trap that prevents any gases within the building drainage system from entering the air handler. This trap must have sufficient depth to withstand any negative air pressure present within the air handler when its blower is operating.

**Radiant panels for cooling:**

There are several type of “radiant” panel products, both pre-assembled, and site-built, that can be used for SENSIBLE cooling only. Because such panels are part of the room’s interior surface, they cannot be allowed to fall below the dewpoint of the room, at
which point condensation would immediately form on the panel. Preventing such condensation will be discussed later in this section.

One example of a partially assembled radiant ceiling panel that can be used for either heating or cooling is shown in figures 5-6 and 5-7.

Figure 5-6: Example of a partially assembled ceiling panel that can be used for radiant cooling. Courtesy of Diego Jendretzki.

Figure 5-7: Example of a partially assembled ceiling panel being installed. Courtesy of Diego Jendretzki.
Chilled water piping:

Chilled water cooling systems require insulation on all piping and other components carrying chilled water. Furthermore, that insulation must be impervious to vapor migration. Failure to provide these details will lead to condensation formation on piping, and quite possibly staining of building surfaces (especially ceilings). Such moisture can also lead to growth of mold and mildew on damp surfaces. Figure 5-8 shows an example of an uninsulated circulator volute carrying chilled water. The volute is covered with condensation and shows evidence of surface corrosion.

Figure 5-8: Condensation on the uninsulated volute of a circulator conveying chilled water.
Figure 5-9 shows an example of chilled water piping insulated with flexible closed-cell foam insulation. Notice that valve bodies and joints are wrapped with insulation either glued or taped at all seams.

Figure 5-9 Example of properly insulated chilled water piping insulated with flexible closed-cell foam insulation.

Figure 5-10 shows an example of a cooling-only chilled water system supplied by a non-reversible water-to-water heat pump.
The heat pump maintains the water temperature in the buffer tank within a suitable range (typically 45 to 55 °F). Since cool water is more dense than warm water, the coolest water accumulates in the lower portion of the buffer tank. Being a dedicated cooling application, the coolest available water is drawn into the distribution system from the buffer tank and distributed to the chilled water air handlers.
a connection low on the tank. Likewise, the somewhat warmer water is drawn into the heat pump from a connection near the top of the tank.

Flow through each air handler is controlled by a zone valve. This valve is mounted on the outlet side of the air handle, where water temperatures are slightly warmer, and thus the potential for condensation is somewhat reduced.

A pressure-regulated circulator modulates speed to main approximately the same differential pressure across the headers as the individual zone valves open and close. The volute of this circulator, and any other circulator conveying chilled water should be insulated. However, the motor can of the circulator should not be insulated due to the need for heat dissipation. In most cases, the heat dissipated through the motor can will keep its temperature above the dewpoint of the surrounding air, and thus free of condensation.

An internal drip pan within each air handler collects condensate from the coil. These drip pans should be piped to appropriate drains within the building, or routed outside. In applications where the air handler is mounted above ceilings, a secondary drain pan is often recommended. This pan should also be piped to a suitable drain. An example of a secondary drain pan under a chilled water air handler is shown in figure 5-11.
To prevent condensation, it is imperative that moisture laden ambient air does not come in contact with the inner pressure vessel of the storage tank. Only buffer tanks with foam insulation should be used for chilled water storage, all seems on the tank jacket should be sealed with aluminum foil tape. All piping connections should be pressure tested, and then sealed with spray foam insulation and wrapped with aluminum foil tape.

**Piping design for radiant cooling**

Figure 5-12 shows a conceptual piping schematic for a chilled water system that provides latent cooling (moisture removal), and ventilation air using a chilled water air handler, as well as sensible cooling using a radiant panel.

![Piping schematic](image)

**Figure 5-12:** A chilled water distribution system for radiant panel cooling along with dehumidification using an air handler.

The temperature controller continually monitors the temperature within the buffer tank, and operates the heat pump as necessary to keep the water temperature within a preset range (typically between 45 and 55 °F).

The chilled water distribution circulator (P1) operates whenever there is a call for cooling. It creates flow of chilled water pass the flow restrictor valve (V1), which induces flow of the coolest available water through the air handler coil.

The air handler handles the latent cooling load, including moisture removal and some sensible cooling of the required ventilation air. It may also be equipped with dampers that regulate the inflow of outdoor air for building ventilation.
The water downstream of valve (V1) is now slightly warmer due to heat absorption from the coil. This water continues through a pair of closely spaced tees, which provide hydraulic separation between circulator (P1) and the radiant panel distribution circulator (P2). The 3-way mixing valve in this subsystem is regulated to keep the water supplied to the radiant panel circuits 3 to 5 °F above the current room dewpoint temperature. This enables the radiant panel to absorb as much sensible heat as possible, and still remain slightly above dewpoint temperature, and thus free of condensation.

The water now returns to the top of the buffer tank where it can be re-chilled by the heat pump as necessary.

The buffer tank allows for zoning of the chilled water cooling system without creating short cycling of the heat pump.

This configuration for sensible cool using a radiant panel or chilled beam, with latent cooling provided by an air handler, could also be used as part of a combined heating and cooling system. These systems are discussed in the next section.

Controllers are available that sense both indoor dry bulb temperature and relative humidity, then process that information to determine the current dewpoint temperature at which moisture in the air would condense. The controller then provides a 0-10 VDC signal to a 3-way motorized mixing valve to maintain the chilled water supply temperature to the radiant panel 3 to 5 degrees above this dewpoint temperature. An example of one such controller is show in figure 5-13.

Figure 5-13: A commercially available dewpoint controller (Honeywell T775).
Section 6: Combined heating and cooling applications

Water-to-water heat pumps equipped with a reversing valve can be used for both winter heating and warm weather cooling. Indeed, such applications leverage the unique ability of heat pumps, and often allow for systems that are more efficient and less costly than using two separate systems; one for heating and the other for cooling.

This section presents several configurations for combined heating and cooling systems using reversible water-to-water heat pumps.

**Heating using radiant panel with single zone chilled-water cooling (Figure 6-1):**

This system provides zoned heating using a variable-speed circulator and zone valves. It also provides single zone cooling using a chilled-water air handler. In the cooling mode, an electrically operated 3-way diverter valve directs the flow of chilled water, leaving the heat pump to the air handler. At the same time, it isolates flow from passing through the buffer tank.

![Diagram](image)

**Figure 6-1:** Multiple heating zones with a single chilled-water cooling zone.
Since there is no buffer tank between the heat pump and chilled water air handler, it is imperative that the air handler is sized to dissipate the full cooling capacity of the heat pump while operating at reasonable chilled water inlet temperatures (typically 45 to 55 °F). Failure to correctly size the air handler in relationship to the heat pump with result in short cycling of the heat pump, or possible safety switch tripping within the heat pump.

Again, all piping and piping components that could convey chilled water must be insulated and vapor sealed.

**Multiple zone heating and multiple zone cooling (Figures 6-2 & 6-3):**

This system provides zoned heating using a variable-speed circulator and zone valves. It also provides multiple zone cooling using chilled-water air handlers. Figure 6-2 shows the system in the heating mode. Figure 6-3 shows the system in the cooling mode.

![Diagram of multiple zone heating and cooling system](image)

**Figure 6-2:** Multiple zone heating and cooling (system shown in heating mode). Grayed-out portion of system is inactive in this mode.

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In the cooling mode, an electrically operated 3-way diverter valve directs the flow of chilled water leaving the buffer tank to the active air handlers. At the same time, it isolates flow from passing through the heating portion of the system. The check valve shown on the space heating return header in figure 6-3 is optional. Its presence helps block any migration of chilled water back into the heating portion of the system when the cooling mode is active.

This system configuration assumes that the variable speed circulator that supplies the zoned heating system is also appropriate (in terms for flow rate and head) to supply the zoned cooling system. However, if the hydraulic characteristics of these two subsystems differ significantly, it may be necessary to select a separate circulator for each. This configuration, which eliminates the need for the diverting valve, is shown in figure 6-4.
Figure 6-4: Using two variable speed distribution circulators. One for cooling mode, the other for heating mode.
Section 7: Using water-to-water heat pumps with thermal storage

Water is one of the best materials available for heat storage. This ability, in combination with water-to-water heat pumps, presents several unique applications.

Off-Peak Thermal Storage Systems:

Some electrical utilities offer the option of time-of-use rates. Generally, these rates lower the price of electrical energy if used during night time hours, and sometimes on weekends or holidays. The utilities objective is to encourage usage that helps lower their peak demand periods, and thus better utilize generating capacity. The customer benefits by significantly reduced energy pricing, if their heating and domestic hot water systems is able to take advantage of these rates. *The key element is a means of thermal storage.* When hydronic heating and cooling distribution systems are used, this storage takes the form of a very well insulated storage tank.

Thermal storage systems are classified according to their ability to meet heating loads using energy purchased and stored during the previous off-peak period. The two common types of system are called **full storage systems** and **partial storage systems**.

In full storage systems, *all* thermal energy used during the subsequent on-peak period is purchased and stored during the off-peak cycle. The storage tank must hold sufficient heat to supply the building’s load through the entire on-peak period, which may be as long as 18 hours. Storage tank volumes of several hundred to more than 1,000 gallons are common in such applications.

In most full storage systems, the output of the heating source, when operating, must be three to four times greater than the design heating load of the building. This is because the heat source only has a few off-peak hours in which to transfer enough heat to supply the building for a 24-hour period.

In partial storage systems, only a portion of the on-peak heating energy is purchased and stored during the off-peak period. Once this energy is depleted, the heat source operate as necessary to maintain comfort. Operating the heat source during the on-peak period uses electricity at the more expensive rate, and thus this should be minimized. However, because it stores only a portion of heat required for the on-peak heat period, a partial storage system often has a lower capacity heat source and a smaller storage tank than a full storage system. This approach lowers initial cost in exchange for a somewhat higher operating cost.

Figure 7-1 shows a schematic for a system that would operate a ground source water-to-water heat pump during off-peak hours to warm a large insulated storage tank.
Figure 7-1: A water-to-water ground source heat pump operates on off-peak electrical rates to charge the thermal storage tank. System provides space heating and domestic water preheating.

A crucial factor in designing this type of system is the upper temperature limit of the heat pump. Most water-to-water heat pumps should not be operated with a leaving load water temperature over 130 °F. However, the ClimateMaster THW series can operate up to 145 °F.

The greater the upper temperature limit of the heat pump, and the lower the acceptable supply water temperature to the distribution system, the smaller the storage tank can be. The following example demonstrates the required size of the storage tank.

Example: A house has off-peak rates available from 11:00 PM to 7:00 AM. On a design day the house looses 28,000 Btu/hr when it is 0 °F outside. The storage tank will be heated by a heat pump that can heat the storage tank to 130 °F. The minimum usable temperature of the distribution system, at design load is 95 °F. Assume the average outside temperature during the on-peak period will be 10 °F. Determine the necessary storage tank size for:

(a) a full storage system
(b) a partial storage system where the tank stores sufficient heat for 10 hours

The first step is to determine how much heat the tank has to store to provide heat during the on-peak period, which in this case is 16 hours long.
The heating load coefficient of the building is determined by the design load and corresponding design temperature difference:

\[
UA_{\text{building}} = \frac{28000 \text{ Btu/hr}}{(70^\circ F - 0^\circ F)} = 400 \frac{\text{Btu}}{\text{hr} \cdot ^\circ F}
\]

The average load of the house during the on-peak period is determined using the average outdoor temperature during that period. In this case:

\[
\text{load} = \left( 400 \frac{\text{Btu}}{\text{hr} \cdot ^\circ F} \right) (70^\circ F - 10^\circ F) = 24000 \text{ Btu/hr}
\]

The total energy that must be supplied from the tank during this 16-hour period is thus:

\[
(24,000 \text{ Btu/hr})(16 \text{ hr}) = 384,000 \text{ Btu}
\]

Based on the allowable temperature change from 95 to 130 \(^\circ\)F, the required volume of the storage tank is:

\[
V = \frac{Q}{8.33(\Delta T)} = \frac{384,000}{8.33(35)} = 1317 \text{ gallons}
\]

This is a large tank. Suppose the system were instead based on partial storage, where the tank would only have to provide storage heat for 10 hours of heating during the on-peak period. The revised storage tank volume would now be:

\[
V = \frac{(24000 \text{ Btu/hr})(10 \text{ hr})}{8.33 \frac{\text{Btu}}{\text{gal} \cdot ^\circ F} (35^\circ F)} = 823 \text{ gallons}
\]

Although still a large tank, the size is significantly smaller than what was required for the full storage scenario.

If the ClimateMaster TWH heat pump was used, and the upper temperature limit of the tank set to 145 \(^\circ\)F, the tank volumes would be reduced by the ratio of the two temperature ranges. In this case:

\[
\text{ratio} = \frac{(130^\circ F - 95^\circ F)}{(145^\circ F - 95^\circ F)} = 0.636
\]
Thus, for the full storage system the tank volume would be:

\[ V = 0.636(1317) = 838 \text{ gallons} \]

The storage tank for the partial storage scenario would now be:

\[ V = 0.636(823) = 523 \text{ gallons} \]

The relatively large storage tanks needed for thermal storage systems can be classified as either open tanks or closed tanks. Each type of tank will be discussed, and a representative schematic using that type of tank presented.

**Open storage tank systems:**

Open tanks allow the air pressure above the water to always equal atmospheric pressure. They are typically constructed of an insulating / structural shell, in which is placed a water tight flexible membrane made of EPDM rubber or other proprietary material. Although these tanks have an insulating cover that minimizes evaporation, there will still be some evaporative water loss from the tank. This requires that the water level be monitored, and when necessary, new water must be added to the tank to maintain a reasonable operating level.

Figure 7-2 shows an example of an open storage tank.

![Figure 7-2 Example of an open storage tank. Product by American Solartechnics.](image)

The piping connections to an open storage tank are typically made through the top, or high on the sidewall, several inches above the water level. This minimizes any potential leakage from submerged fittings.
The air space above the water serves as the expansion space for the water in the tanks and remainder of the system as that water is heated and cooled.

Water from the storage tank can usually be circulated directly through the heat pump, assuming it has a copper, cupronickel, or stainless steel condenser. The details for this are shown in figure 7-3.

![Diagram of an open tank thermal storage system used with a water-to-water heat pump.](image)

Figure 7-3: Example of an open tank thermal storage system used with a water-to-water heat pump.

Cooler water from near the bottom tank is drawn upward through piping that exits the sidewall of the tank above the water level. The dip tube is primed by first closing an isolation flange on the circulator, and then forcing water a line pressure into the priming valve. The rapid flow of water will flush air from the dip tube assembly, filling it with water. This water will remain in the portion of the dip tube piping that’s above the water level provided there are no air leaks in the piping. To reduce head loss on the inlet side of the circulator, the dip tube piping should be as short as possible, and contain minimal fittings.
The circulator supplied by the dip tube should be located as low as possible relative to the water level in the tank. This increases the static head at the circulator inlet and reduces the possibility of cavitation. Because it operates with water from an open tank, the circulator must be rated for use in an open system. Circulators with volutes and impellers constructed of bronze, stainless steel, or polymer materials are available for such applications. Cast-iron circulator should not be used.

The heated water returning to the tank passes through a tee located just under the water surface in the tank. The purpose of this fitting is to inject the water horizontally rather than vertically, and thus help preserve temperature stratification within the tank. Again, provided there are no air entry points in this upper piping, it should remain filled, even when the circulator is off.

Heat is extracted from the tank for both domestic water preheating and space heating. The heat is extracted through coiled copper tube heat exchanger suspended within the tank. An example of such a heat exchanger is shown in figure 7-4.

![Figure 7-4: Coiled copper tube heat exchanger designed to supply domestic water heating or space heating. This coil is suspended within the open storage tank.](image)

Because the space heating sub-system draws its heat through this coil, and does not directly use tank water, it can be designed as a closed loop sub-system. As such it must contain its own expansion tank, air separator, make-up water assembly, and pressure relief valve.
Closed storage tank systems:

The system shown in figure 7-1 uses a closed / pressurized storage tank. Such tanks are available from various sources. Although they can be custom made for a given system, such fabrication comes at significantly increase price. Instead, it is advantageous to use pressure-rate tanks that are mass produced for other applications. One example is a “repurposed” propane storage tank. Companies that offer such tank can usually add fittings that are ideally placed and sized for the application. Figure 7-5 shows an example of “stacked” 500 gallons tanks. This configuration is designed to minimize the required “footprint” of the 1000 gallon storage system.

Once installed and piped, the tank piping connections should be pressure tested. After this the tank must be very well insulated. One possible material is site-applied spray foam. A minimum of 4-inch thickness is recommended. Another alternative is to frame walls around the tank, and fill the space with poured or blown insulation such as cellulose, foam beads, or fiberglass. Always verify that the insulation material used is compatible with the maximum possible temperature the tank will operate at.
Always check to see if local codes mandate that the tank be ASME certified. This certification may apply to pressurized storage tanks of 120 gallon or more in volume. When required, will increase cost.

Closed storage tanks have the following advantages:

- No heat exchanger is required between the tank water and the distribution system
- Water losses are extremely low, and typical of any closed loop hydronic system.

One disadvantage of a closed tank is that it requires the system to have a substantially larger expansion tank. The size of this tank must be calculated based on the total system volume and range of temperature.

All systems with large storage tanks should be planned such that the tank can be placed as well as removed if ever necessary, without major disruption of the remainder of the system, or the building in which the tank is located.
Section 8: Using water-to-water heat pumps with solar collectors

Interest in solar thermal systems shares the spotlight with interest in geothermal heat pump systems. There are several ways in which these renewable heat sources can be combined.

Before discussing combined systems, we will look at three common solar thermal subassemblies. All involve a collector array, piping and pumping components and a storage tank. These systems differ in the way they protect the collector array and exposed piping from freezing.

Closed-loop antifreeze-based systems with *internal* heat exchanger:

The solar thermal subsystem shown in figure 8-1 uses a closed piping loop filled with antifreeze solution. When the collector is sufficiently warm, the solution is circulated between the collector array and a coiled heat exchanger within the storage tank. Flow is created by a small circulator that is controlled by a differential temperature controller. The latter continually measures the temperature near the outlet of the collectors, and compares it to the temperature in the lower portion of the storage tank. When the collector array reaches a temperature that’s a few degrees above the storage tank, the circulator is turned on. When this differential drop to about 2 or 3 °F the circulator is turned off.

![Figure 8-1: Solar thermal subsystem using antifreeze and a storage tank with internal heat exchanger.](image-url)
Closed-loop antifreeze-based systems with *external* heat exchanger:

The system shown in figure 8-2 also uses antifreeze to protect the collector array. However, this system uses an external brazed plate heat exchanger to transfer heat to the storage tank. The external heat exchanger requires another small circulator between it and the storage tank. This heat exchanger operates whenever the collector circulator operates.

![Solar thermal subsystem using antifreeze and an external heat exchanger.](image)

**Figure 8-2: Solar thermal subsystem using antifreeze and an external heat exchanger.**

**Drainback solar thermal subsystem:**

The solar thermal subsystem shown in figure 8-3 does not use antifreeze to protect the collectors from freezing. Instead, it relies on “drainback” freeze protection. Whenever the collector circulator is not operating, all water in the collector array and exposed piping drains back to the space at the top of the storage tank. As the water drains, the air in this space goes up into the collector array. For this system to operate properly, the collectors and all exposed piping must be pitched a minimum of \(\frac{1}{4}\)-inch per foot in the direction of drainage.
Figure 8-3: Solar thermal subsystem using drainback freeze protection.

All three types of solar thermal subsystems could potentially be used in combination with water-to-water heat pumps.
One possible heating-only system that combines heat input from a solar thermal system with that from a heat pump is shown in figure 8-4.

Figure 8-4: Combined use of water-to-water heat pump with solar thermal subsystem.

This system has several potential operating modes. For example, the water-to-water heat pump could be operated on “off-peak” electrical rates as discussed in the previous section. The solar thermal subsystem could also add heat to the system - obviously during the day. This allows the two heat input subsystems to complement each other over a 24-hour period.

The load side of the system includes a subsystem for pool heating using a pool-specific heat exchanger. This allows the pool to be heated using heat supplied by either heat source.

A close-up view of the load side of the tank and associated piping is shown in figure 8-5.
Figure 8-5: Closeup of load side piping used in the system of figure 8-4.
Another unique system concept is shown in figure 8-6.

Figure 8-6: Solar assisted ground source heat pump with dual operating modes for collector array. System shown in heating mode.

Here, the solar collector array can be used to supply low temperature heat to supplement the earth loop, or high temperature heat to heat domestic water. The diverter valve determines which load the collector array supplies.

For example, during periods of relatively low solar radiation it would be advantageous to operate the collector array in parallel with the earth loop. The low collector inlet temperatures would allow the collectors to operate at reasonably good efficiency.

However, during brighter sky conditions it may be better to operate the collector array so that it only supplies heat to heat exchanger in the domestic water tank.

A diverter valve is used to determine which load the solar collector array is connected to.
In this system, the antifreeze solution must be formulated to provide freeze protection of the collector array, which will likely experience lower temperatures than the earth loop.

If a heat pump with a desuperheater is used, it can provide heat input to the domestic water tank during either heating or cooling modes of operation.

When the heat pump is operating in the cooling mode, it would be detrimental to add heat to the earth loop from the solar collectors. Thus, the collector subsystem could only provide heat to the domestic water tank during this mode. Figure 8-7 shows the system in cooling mode.

Figure 8-7: System operating in cooling mode. All heat from solar collectors is routed to domestic water tank.
Another possible operating mode in climates with minimal cooling load would be to operate the collector array during late summer and fall to add heat to the soil surrounding the earth loop. Although this concept is feasible, its success is very dependent on the earth loop and surrounding geology at a given site. If there is no aquifer or other subterranean water in the vicinity of the earth loop some storage of solar heat input is likely. This would likely be a better prospect when a horizontal earth loop is used. However, any subterranean water is likely to be too much of a heat sink to make this practical.

One other potential operating mode of this system is to use the earth loop as a “heat dump” for the solar collectors in the event the domestic water storage tank reaches its upper limit. Again, this is more practical in Northern climates with minimal cooling loads. It would not be recommended for climates with significant cooling load.
Section 9: Multiple water-to-water heat pump systems

As the size of the load increases, it often makes sense to use two or more water-to-water heat pumps operating in stages, rather than a single heat pump sized to the total load. This is especially true when the operating power is 240 VAC single phase. Heat pumps with nominal heating capacity greater than approximately 6-tons (72,000 Btu/hr) place high current demands on such power supplies, especially when their compressor is starting. By dividing this total capacity into two smaller units, and staggering their starts, the inrush current demand is significantly reduced.

The advantages of multiple water-to-water heat pump systems include:

• Better matching of capacity to load in both heating & cooling mode

• Reduces buffer tank size

• Provides partial capacity if one heat pump is down for service.

• Allow smaller and lighter units to be used in comparison to a single large chiller

• May allow for simultaneous heat and cooling of dual buffer tank system

• Allows for vertical racking to conserve floor space in mechanical room

• Reduces inrush current with staggered starting

• Allows the possibility of variable flow in earth loop

Although it is possible to pipe the earth loop so that flow passes through each of the heat pumps in a multiple heat pump system whenever the earth loop circulator is operating, this does waste pumping energy when one or more of the heat pumps is off.

A better approach is to provide hydraulic separation between the earth loop and the source side (assuming heating mode) of the heat pumps. An ideal device for doing this is called a hydraulic separator. The placement of this device is shown in figure 9-1.
Figure 9-1 placement of a hydraulic separator between the earth loop and multiple heat pump array.

The internal construction of a hydraulic separator is shown in figure 9-2. The vertical “barrel” of the separator typically has a diameter about 3 times that of the connecting piping. This allows the vertical flow velocity within the barrel to be about 1/9th that in the connecting piping. A typical vertical flow velocity within the barrel is about 0.4 ft/sec. At this speed, the flow creates extremely little dynamic head loss as it passes vertically through the barrel. This is akin to the very small pressure drop through a pair of closely spaced tees. The very small head loss through the separator prevents the pressure dynamics established by the circulator(s) on the left side of the separator from influencing the pressure dynamics of the circulator(s) on the right side of the separator. In the example shown in figure 9-1 the earth loop circulator is hydraulically isolated from the circulator(s) serving the heat pump array - even though they share the same fluid.
The low flow velocity within the separator also allows most air bubbles to easily rise upward, even with downward moving flow. The bubbles move upward into the chamber above the active flow zone. A float-type air vent at the top of the hydraulic separator eventually ejects this accumulated air from the system. The stainless steel mesh seen within the separator in figure 9-2 acts as a coalescing media to expedite the formation and capture of microbubbles. Thus, the hydraulic separator also serves as a high performance air separating device, a vital component in any hydronic system.

The low flow velocity also allows dirt particles being carried along by the flow to drop out of the flow stream and accumulated in the lower sediment chamber. The drain valve at the bottom of this chamber is periodically opened to flush out an accumulated dirt. This third function of the hydraulic separator is very desirable in earth loop heat pump systems, given that it is virtually impossible to keep all dirt out of the piping as it is installed.
In summary, a modern hydraulic separator provides the following desirable functions within the system.

- hydraulic separation
- high performance air separation
- high performance dirt separation

Many of the schematic in the remainder of this section make use of hydraulic separators.

**Controlling multiple on/off heat pumps:**

Multiple on/off water-to-water heat pumps can be staged on and off using controllers designed for multiple boiler systems. An example of such a controller is shown in figure 9-2a.

![Figure 9-2a: A multiple boiler controller than can control up to 4 on/off heat sources as well as provide outdoor reset control and heat source run time equalization.](image)

Upon a demand for heating, this controller measures the current outdoor temperature, and then uses this temperature along with its settings to calculate the ideal target supply water temperature to the space heating distribution system using outdoor reset control. An example of a typical outdoor reset control function is shown in figure 9-2b.
Figure 9-2b: Example of a typical outdoor reset function for a low temperature space heating system.

It's also possible to use multi-unit staging control in combination with 2-stage heat pumps. A two-stage heat pump has two compressors that can be independently operated. In such cases, the operating order would typically be:

a. heat pump #1/compressor 1
b. heat pump #1/compressor 2
c. heat pump #2/compressor 1
d. heat pump #2/compressor 2

In addition to outdoor reset control, a multi-stage controller can rotate the operating order of the heat sources so that each stage accumulates about the same number of operating hours over an extended time. This allows each stage to be serviced at the same time when service is bases on the number of operating hours.

**Flow control through multiple heat pumps:**

To minimize pumping power, there should only be flow through a water-source heat pump when it is operating. There are two common ways to do this:

1. Use a smaller circulator on the loop side of each heat pump. This circulator only operates when its associated heat pump is operating.
2. Install a zone valve (or motorized ball valve) on the loop side of each heat pump. This valve only opens when its associated heat pump is operating. A single variable speed, pressure-regulated circulator provides flow for the loop side of each heat pump in the array.

A piping schematic showing the use of individual circulators at each heat pump is shown in figure 9-3.

Figure 9-3: Use of individual circulators with internal check valves on the earth loop side of each heat pump.
The header piping that supplies flow to each heat pump from the hydraulic separator should be sized for a maximum flow velocity of 2 feet per second. This keeps head loss to a minimum, and allows almost equal flow through each identical heat pump regardless of its position along the header. It also eliminates the need for reverse return piping.

The flow rate on the right side of the hydraulic separator will vary depending on the number of active heat pumps. The flow on the left side of the separator is completely independent of this flow.

A system using individual zone valves at each heat pump along with a single variable speed pressure-regulated circulator is shown in figure 9-4.

Figure 9-4: Use of individual zone valves at each heat pump in combination with a variable speed pressure-regulated circulator.
Figure 9-5 shows both sides of a multiple water-to-water heat pump system. Flow through both the evaporators and condensers is controlled by the combination of zone valves (or motorized ball valves) and an associated variable speed, pressure-regulated circulator. A hydraulic separator is used as the interface to both the earth loop and load side of a non-zoned distribution system.

Figure 9-5: Piping using zone valves and variable speed, pressure-regulated circulator on both sides of a multiple heat pump array. Distribution system is assumed to be a single zone.
If the distribution system is zoned, the hydraulic separator on the load side of the system should be replaced with a buffer tank as shown in figure 9-6.

Figure 9-6: Piping using zone valves and variable speed, pressure-regulated circulator on both sides of a multiple heat pump array. Distribution system is assumed to be zoned, therefor a buffer tank is used rather than a hydraulic separator.

The graph in figure 9-7 shows how the variable speed, pressure-regulated circulator operates to maintain constant pressure between the supply and return headers. When one of the zone valves closes, the differential pressure across the headers attempts to increase. The circulator senses this change, and responds with a speed reduction that compensates for the attempted change in differential pressure. Although there is a slight departure from the set differential pressure as the circulator’s internal controls sense and compensate for changes over a period of a few seconds using a PID.
algorithm. The net result is nearly constant differential pressure. This is a very desirable condition.

Figure 9-7: Sequence as a pressure-regulated circulator changes speed to compensate for closing or opening zone valves on heat pumps.

Multiple heat pump arrays can be constructed of non-reversible or reversible heat pumps. In the latter case, the system can be configured such that any given heat pump can supply heating or cooling as determined by the building loads. One option for doing this is shown in figure 9-8.
Figure 9-8 An array of reversible water-to-water heat pumps supplies both heated and chilled buffer tanks. Two circulators with internal check valves are used on the load side of each heat pump. One runs in the heating mode, the other in the cooling mode.

Because they have very slow internal flow velocities, buffer tanks also serve as hydraulic separators between the heat pump array and load circulators.

A system controller would continually monitor the loads in the building, and calculate the necessary target temperature for each buffer tank. Based on these tanks temperatures, and the rate at which they are changing, the controller would determine which heat pumps need to run in the heating or cooling mode at any given time. Whenever a given heat pump is turned on, the appropriate load side circulator (e.g. for heating or cooling) is also turned on.
Any heat pump operating in the heating mode is extracting heat from the headers on the left side of the heat pump array. Any heat pump operating in the cooling mode is adding heat to these headers. It is possible that the rate of heat extraction is close to the rate of heat addition. In such cases the load on the earth loop is only the difference between these two rates. If the earth loop has a variable speed circulator, its speed can be reduced to the point where it supplies the net amount of source heat or heat dissipation effect needed. Such operation could significantly reduce the electrical energy use of the earth loop circulator.

Another possible heat pump configuration is shown in figure 9-9. Here, a single heat pump is connected directly between the heated and chilled buffer tanks. The would be the first heat pump to operate whenever there is a simultaneous demand for both heating and cooling. Since both chilled water and heated water are desired effects, the effective COP of this heat pump would be double that of a heat pump providing only heating or only cooling.
Figure 9-10: Use of a fixed lead heat pump between buffer tanks to provide simultaneous heating and cooling.

As the required heating and cooling loads change to the point where this single heat pump cannot provide both, the heat pumps in the upper array would be turned on in the appropriate modes to provide the necessary supplemental heating and cooling.
Section 10: DHW heating & heat recovery applications

Water-to-water heat pumps can be used for dedicated domestic water heating.

Some heat pumps, such as the ClimateMaster THW unit have a dedicated domestic water heating mode. When operating in this mode, the full heating output of the heat pump is used to directly heat domestic water. The THW heat pump uses a secondary stainless steel heat exchanger for domestic water heating. This provides double wall separation between the refrigerant and the domestic water being heated. This concept is shown in figure 10-1.

![Diagram of ClimateMaster THW heat pump using secondary heat exchanger for domestic water heating.](image)

A diverter valve within the THW unit is energized during the domestic water heating mode to direct all heat output to the domestic water heating load. Output to the space heating distribution system is temporarily suspended during this mode. However, if a buffer tank is being used between the heat pump and space heating loads, heat flow can continue from the buffer tank to the loads while domestic water is being heated.
ClimateMaster also offers the TDW heat pump for domestic water heating. The TDW is available in 15,000 and 36,000 Btu/hr nominal capacities. The double wall, vented load heat exchanger in the TDW is designed specifically for use with potable water. It can be directly connected to an electric water heater as shown in figure 10-2.

![Figure 10-2: Typical piping for a ClimateMaster TDW heat pump.](image)

The TDW unit is a high temperature water-to-water heat pump. It is capable of up to 145 °F leaving load water temperature.

The temperature controller for the TDW has many unique features. Among these is the ability to send power to the electric water heater allowing it to operate in the case of a fault by the TDW unit. The electric water heater can also be selected by placing the TDW controller in the "emergency heat" mode. The controller prevents the simultaneous operation of the TDW and the electric heater's elements, allowing the TDW and electric water heater to share a single power circuit.
The controller in the TDW heat pump also has intelligent set point reduction logic which can reduce the set point temperature to prevent the unit from faulting out in situations such as a slightly dirty heat exchanger and notify the building occupant that the unit is operating under reduced capabilities and that attention is needed.

The TDW temperature set points are programmable to take advantage of lower set points when homeowners are away or where time-of-use electrical rates are available.

**Other DHW solutions:**

Heat pumps that are not designed or certified for direct contact with domestic water can also be used, provided that domestic water does not pass directly through the heat pump. One approach that allows this is shown in figure 10-3.

![Figure 10-3: A non-reversible water-to-water heat pump used for heating domestic hot water.](image)
The non-reversible heat pump supplies heat to the buffer tank. This tank provides the thermal mass to allow the rate of hot water delivery to be temporarily higher than the rate of hot water production. Whenever there is a demand for domestic hot water, a flow switch immediately turns on the circulator on the right side of the tank to circulate heated water from the buffer tank through the external brazed plate heat exchanger. This heat exchanger immediately transfers heat to the cold domestic water entering the other side. When properly sized, it will be able to heat the domestic water to within a few degrees of the buffer tank temperature. If this leaving temperature is still too low for the intended use, the water can be further heated by an auxiliary water heating device. The external heat exchanger can be serviced or replaced if ever necessary due to impurities in the domestic water.

Another possible way to heat domestic water with a water-to-water heat pump is to use an indirect water heater as shown in figure 10-4.

Because water-to-water heat pumps cannot achieve water temperatures above approximately 130 to 145 °F (depending on make and model), it is important to select and indirect water heater with a large internal heat exchanger. The larger the surface

**Figure 10-4: Use of indirect water heater with water-to-water heat pump.**
area of the internal heat exchanger, the greater the rate of heat transfer for a given temperature difference between the entering water from the heat source, and the average temperature of the tank water. The internal heat exchanger must be large enough so that the heat pump can transfer its full heat production without exceeding its upper water temperature limit (130 °F for most heat pumps).

Internal heat exchangers may be configured as an internal coil, (as shown in figure 10-2), or as a tank-within-a-tank. An example of the latter is shown in figure 10-5. In this configuration, domestic water is held within the inner stainless steel tank. Heat water from the heat pump circulates in the space between this inner tank and the outer steel shell. If necessary, additional heat input to the tank can come from a boiler and/or a solar collector array. This tank also has a provision for an electric heating element that can be operated during off-peak hours, or whenever necessary to maintain an acceptable domestic hot water delivery temperature.

Figure 10-5: Example of a tank-within-a-tank indirect water heater with optional input from a solar collector array. Tank by Triangle Tube.

Another hardware option is to use a “reverse” indirect water heater in combination with the water-to-water heat pump. A schematic for this approach is shown in figure 10-6.
Figure 10-6: Use of a “reverse” indirect tank for domestic water heating. This tank can also serve as a buffer tank for space heating loads.

A reverse indirect tank holds domestic water within several internal copper coils that are submerged within an insulated tank shell. Heated water from the heat pump flows through the tank shell and around these coils. An example of such a tank is shown in figure 10-7.
When properly selected, this type of tank can provide high rates of heat transfer relative to other indirect tank configurations.

Because the water in the tank shell is “system water” rather than domestic water, this tank could also serve as a buffer tank for a zoned hydronic space heating system. An example of such a configuration is shown in figure 10-8.
Figure 10-8: Using the reverse indirect tank for both domestic water heating and as a buffer tank for a zoned space heating distribution system.

The tank serves as a hydraulic separator between the heat pump load-side circulator, and the circulator used for space heating. The piping between the tank and the mixing valve for space heating should have minimal head loss. It should be sized for a maximum flow velocity of 2 feet per second, and kept as short as possible.

When the tank serves as a buffer tank and domestic water heater, priority is given to the latter. Thus, when the space heating load is active, and the tank water temperature cannot be maintained above a set lower limit based on acceptable domestic hot water delivery, the space heating load will be temporarily shed by turning of the distribution circulator until the tank water temperature recovers.
Heat recovery applications:

Water-to-water heat pumps can also be used in situations where both chilled water and heated water are needed for processing.

One example is in gelatin production, which requires both ice and boiling water. One or more non-reversible water-to-water heat pumps can be configured between two storage tanks as shown in figure 10-9.

![Figure 10-9](image)

Figure 10-1: A non-reversible water-to-water heat pump configured to simultaneously produce both heated and chilled water for food processing.

The chilled water reduces the load on ice making equipment. The heat water reduces the load on the auxiliary water heaters required to eventually boil the water.

In such applications it is important to verify that the heat pump is suitable for direct contact with potable water, and that any impurities in this water are within acceptable limits as established by the heat pump manufacturer.
Appendix A: Piping Schematic Symbol Legend

NOTES:
1. Installer is responsible for all equipment selection & detailing as required by local codes
2. All piping should be sized for a maximum flow velocity of 4 feet/second
3. Install a minimum of 12 diameters of straight pipe upstream of all circulators and check valves
4. Install isolating flanges or isolating valves on all circulators
5. An anti-scald mixing valve is recommended if the DHW temperature is set above the 115°F
Appendix B: Additional Sources of Information on Hydronic System Design

1. Publications:
   a. Plumbing & Mechanical magazine (www.pmmag.com)
   b. PM Engineer magazine (www.pmengineer.com)
   c. Contractor magazine (www.contractormag.com)
   d. Radiant Living magazine (www.radiantlivingmag.com)

2. Associations:
   a. Radiant Panel Association (www.radiantpanelassociation.com)
   b. Hydronics Industry Alliance (www.myhomeheating.com)
   c. Hydronic Heating Association (www.comfortableheat.net)

3. Other hydronic heating Web sites:
   a. www.hydronicpros.com
   b. www.heatinghelp.com
   c. www.healthyheating.com
   d. www.radiantandhydronics.com

4. Technical Reference Books:

5. Hydronics Design Software:
   b. LoopCAD: (www.loopcad.com)
   c. Wright-Suite (www.wrightsoft.com)