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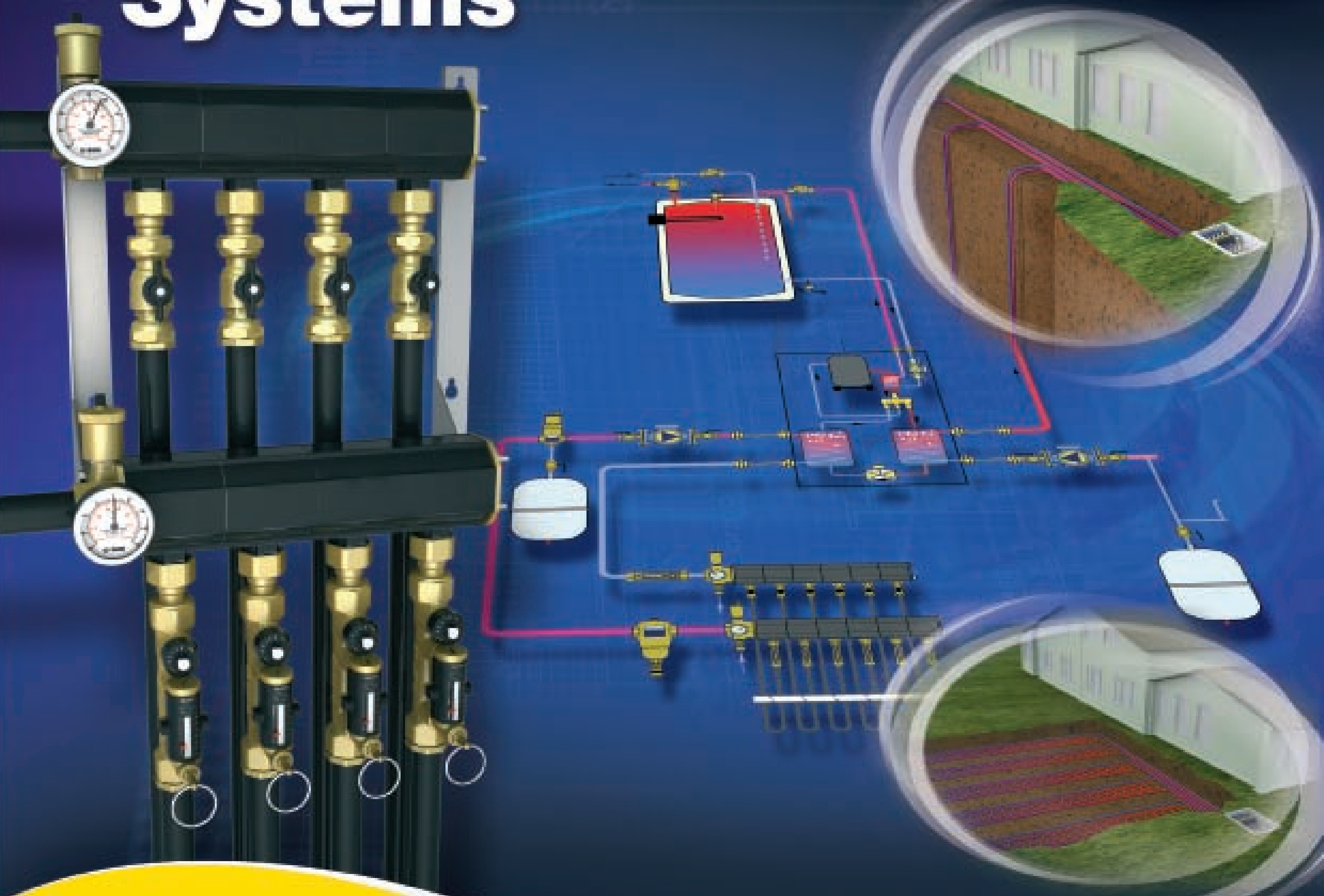
Geo-Hydronic Systems



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from
Caleffi Hydronic Solutions

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Dear Hydronic Professional,

Welcome to the 9th edition of idronics, Caleffi's semi-annual design journal for hydronic professionals.

Heat pumps have been around for decades. However, due to advances in product design, public interest in energy conservation and recently enacted government incentives, interest in heat pumps has risen rapidly. Geothermal heat pump shipments, for example, have increased nearly 4 fold in the USA since 2003.

In this issue we explain the basics of heat pump operation and describe several types of heat pumps. The discussion then turns to use of modern hydronics to enhance the efficiency and comfort provided by these heat pumps. System configurations ranging from simple single-zone/heating-only systems, to large multi-heat pump heating and cooling systems are shown. Specific information on sizing components such as buffer tanks, expansion tanks and circulators is also provided. In short, this issue of idronics shows you how to "leverage" the advantages of hydronics for optimizing the heating and cooling performance of heat pump systems.

We encourage you to send us feedback on this issue of idronics by e-mailing us at idronics@caleffi.com.

If you are interested in previous editions of idronics, please go to www.caleffi.us where they can be freely downloaded. You can also register online to receive future hard copy issues.

Mark Olson
General Manager & CEO

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GEO-HYDRONIC SYSTEMS

1. HEAT PUMP BASICS

WHAT IS A HEAT PUMP?

Heat pumps are devices for converting low-temperature heat into higher-temperature heat. The low-temperature heat is gathered from some material called the "source," and then concentrated and released into another material called the "sink."

When used to heat buildings, heat pumps can gather low-temperature heat from sources such as outdoor air, ground water, lakes or ponds, or tubing buried within the earth. All of these sources provide "free" low-temperature heat.

Heat pumps that extract low-temperature heat from outside air are relatively common in North America. They are typically called "air-source" heat pumps. The vast majority of such devices currently in service are configured to deliver higher-temperature heat through a forced-air distribution system within the building. This leads to the more specific classification of "air-to-air heat" pump. Recent developments have made it possible to use air-source heat pumps in combination with hydronic distribution systems. Since these units use water as the means of heat delivery, they are classified as "air-to-water" heat pumps.

Heat pumps that extract low-temperature heat from lakes, ponds, wells or tubing buried in the earth use water or a mixture of water and antifreeze to convey heat from those sources to the heat pump. They are thus classified as "water source" heat pumps. Those that deliver this heat through a forced-air system are more specifically called water-to-air heat pumps. Those that deliver their heat using a hydronic distribution system are known as water-to-water heat pumps.

The vast majority of the low-temperature heat contained in outside air, ground water and soil originated as solar energy. This energy was absorbed during warmer weather. As summer turns to fall and winter, this heat is slowly dissipated to the outside air. However, even in winter some of this low-temperature heat can be gathered using the efficient refrigeration systems in modern heat pumps.

Heat absorbed by ground water or soil can take several months to dissipate back into the atmosphere, even in harsh winter climates where outside air temperatures drop quickly in fall and remain low during winter. Heat stored in the earth is typically at temperatures significantly warmer than the outside air temperature during fall and winter. This presents a favorable situation for water-source heat pumps since their thermal performance is enhanced at higher entering source water temperatures. This situation has led to rapid growth in the use of ground source heat pumps, which are discussed in detail in section 3.

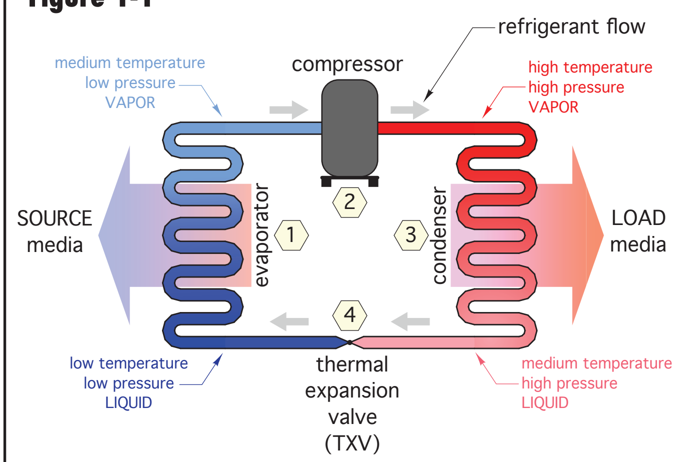
THE REFRIGERATION CYCLE

The refrigeration cycle is the basis of operation of all vapor-compression heat pumps. During this cycle, a chemical compound called the refrigerant circulates around a closed piping loop passing through all major components of the heat pump. These major components are named based on how they affect the refrigerant passing through them. They are as follows:

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

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

Figure 1-1



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

The cycle begins at station (1) as cold liquid refrigerant within the evaporator. At this point, the refrigerant is colder than the source media (e.g., air or water) passing across the evaporator. Because of this temperature difference, heat moves from the higher-temperature source media into the lower-temperature refrigerant. As the refrigerant absorbs this heat, it changes from a liquid to a vapor (e.g., it evaporates). The vaporized refrigerant continues to absorb heat until it is slightly warmer than the temperature at which it evaporates. The additional heat required to raise the temperature of the refrigerant above its saturation temperature (e.g., where it vaporizes) is called *superheat*, and it also comes from the source media.

This vaporized refrigerant then flows on to the compressor at station (2). Here a reciprocating piston or a rotating scroll driven by an electric motor compresses the vaporized refrigerant. This causes a large increase in both pressure and temperature. The electrical energy used to operate the compressor is also converted to heat and added to the refrigerant. The temperature of the refrigerant gas leaving the compressor is usually in the range of 120° to 170°F depending on the operating conditions.

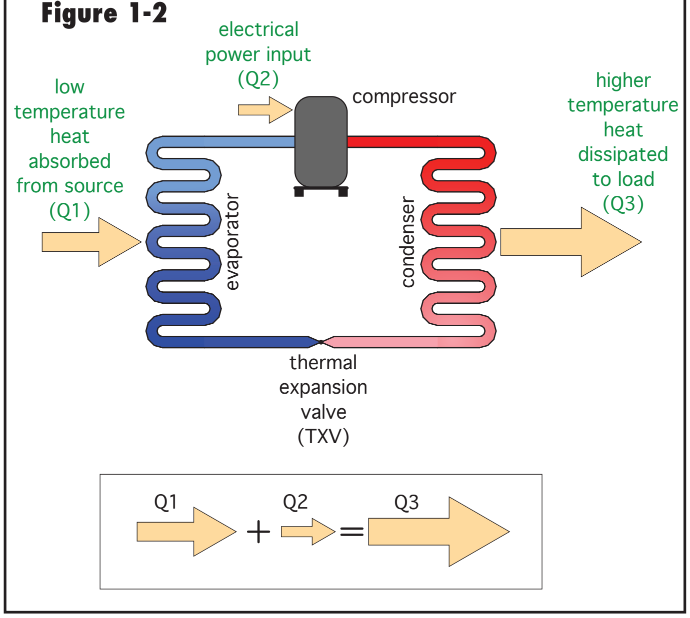
The hot refrigerant gas then flows into the condenser at station (3). Here it transfers heat to a stream of water or air (e.g. the load media) that carries the heat away to the load. As it gives up heat, the refrigerant changes from a high-pressure, high-temperature vapor into a high-pressure, somewhat cooler liquid (e.g., it condenses).

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

The refrigeration cycle remains in continuous operation whenever the compressor is running. This cycle is not unique to heat pumps. It is used in refrigerators, freezers, room air conditioners, dehumidifiers, water coolers, vending machines and other heat-moving machines. The average person is certainly familiar with these devices, but often takes for granted how they operate.

Figure 1-2 shows the three primary energy flows involved in the refrigeration cycle. The first energy *input* is low-temperature heat absorbed into the refrigerant at the evaporator. The second energy *input* is electrical energy flowing into the compressor whenever it is operating. The third energy flow is the heat *output* from the condenser.

Figure 1-2



The first law of thermodynamics dictates that the total energy input rate to the heat pump must equal the total energy output rate. Thus, the sum of the low-temperature heat absorption rate into the refrigerant at the evaporator, plus the rate of electrical energy input to the compressor, must equal the rate of energy dissipation from the refrigerant at the condenser. This is depicted by the arrows in Figure 1-2.

NON-REVERSIBLE VS. REVERSIBLE HEAT PUMP

Heat pumps always move heat from a lower-temperature media to another media at a higher temperature. The basic "non-reversible" heat pump described in Figures 1-1 and 1-2 can be used as a dedicated heating device or a dedicated cooling device.

As a dedicated heating device, the evaporator side of the heat pump will always gather low-temperature heat from some source where that heat is freely available and abundant. The condenser side will always deliver higher-temperature heat to the load.

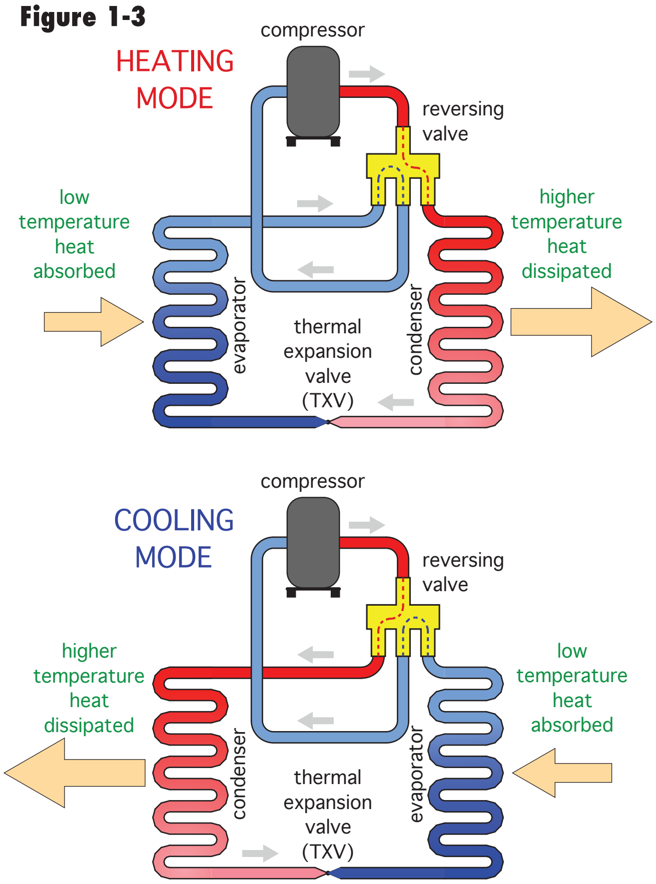
One example would be a heat pump that always delivers energy for space heating a building. Another would be a heat pump that always delivers energy to heat domestic water.

As a dedicated cooling device, the evaporator side of a non-reversible heat pump always absorbs heat from a media that is intended to be cooled. Examples would be heat extraction from a building during warm weather or heat extraction from water that will eventually be converted into ice. The condenser side of such a heat pump will always dissipate the unwanted heat to some media that can absorb it (e.g., outside air, ground water or soil).

There are many applications where non-reversible heat pumps can be applied. However, one of the most unique benefits of modern heat pumps is that the refrigerant flow can be reversed to immediately convert the heat pump from a heating device to a cooling device. Such heat pumps are said to be "reversible." A reversible heat pump that heats a building in cold weather can also cool that building during warm weather.

Reversible heat pumps contain an electrically operated device called a reversing valve. When the reversing valve is not energized, refrigerant flow is such that the heat pump is in heating mode. When low-voltage power is applied to the reversing valve, it moves an internal element that changes the direction of refrigerant flow through both the evaporator and condenser, as shown in Figure 1-3. The reversing valve effectively "swaps" the functions of these devices. The heat exchanger that serves as the evaporator in the heating mode serves as the condenser in the cooling mode. Similarly, the other heat exchanger that served as the condenser in the heating mode acts as the evaporator in the cooling mode.

Figure 1-3



The most common configuration for a reversible heat pump is one in which two thermal expansion valves are used in combination with two check valves. One thermal expansion valve functions during the heating mode while the other functions during the cooling mode. Some heat pumps also use a single electronically controlled "bi-directional" thermal expansion valve. For simplicity, the heat pump refrigeration piping diagrams shown assume a single thermal expansion valve.

CATEGORIES OF HEAT PUMPS

Heat pumps are categorized based on the media from which they extract heat, as well as the media to which they dissipate heat. The most common categories are:

- Air-to-air heat pumps
- Air-to-water heat pumps
- Water-to-air heat pumps
- Water-to-water heat pumps

The first word in the category name is the media from which low-temperature heat is extracted. The word following "to" is the media to which higher-temperature heat is dissipated.

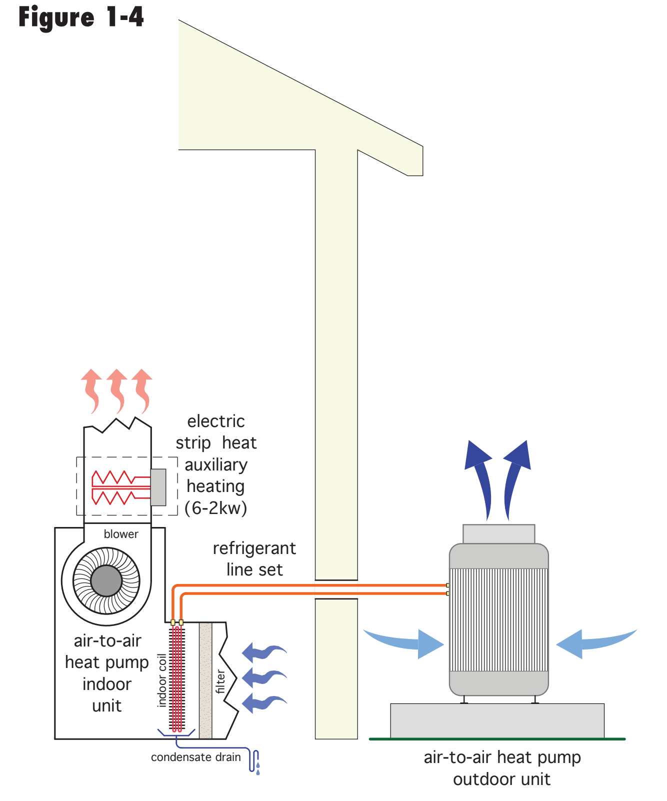
AIR-TO-AIR HEAT PUMPS

The most common type of heat pump used for residential heating and cooling in North America is the air-to-air heat pump. In heating mode, an air-to-air heat pump absorbs low-temperature heat from outsider air and delivers higher-temperature heat to inside air. Figure 1-4 shows a typical configuration for an air-to-air heat pump used for home heating.

Most air-to-air heat pumps have an indoor unit as well as an outdoor unit.

When operating in the heating mode, the outdoor unit serves as the evaporator. It contains a large air-to-refrigerant heat exchanger that consists of several feet of copper or aluminum tubing attached to closely spaced aluminum fins. This assembly is called the outside coil, and during the heating mode it contains the evaporating refrigerant. A fan draws air surrounding the outside unit through this coil and extracts low-temperature heat from it. The cooled air then passes through the fan and is discharged vertically away from the unit. The heat absorbed by the refrigerant in the coil causes it to vaporize. This vapor then passes to the compressor, which is also located in the outside unit. The hot discharge

Figure 1-4



gas from the compressor flows through insulated copper tubing to the indoor unit.

The indoor unit contains a refrigerant-to-air heat exchanger called the inside coil. It also contains a blower that creates air flow across the inside coil and onward through a ducted distribution system within the building. The inside coil serves as the condenser when the heat pump is operating in the heating mode. As hot refrigerant gas from the outdoor unit passes across the indoor coil, it gives up heat to the airstream and eventually condenses into a liquid. This liquid travels back to the outdoor unit through another copper tube. It passes through the thermal expansion valve where it is returned to the same starting conditions, and it is ready to begin the cycle.

Some indoor units are also equipped with an electrical resistance heating assembly called a "strip heater." This assembly contains several electric heating elements that can be turned on to boost the heating capacity of the heat pump if necessary.

When cooling is needed, a reversing valve within the system effectively swaps the function of the indoor and outdoor coils. The inside coil becomes the evaporator, while the outside coil serves as the condenser. Indoor air is cooled and dehumidified as it passes through the inside coil. The heat absorbed from this air, as well as the heat generated by the compressor, is rejected to the atmosphere as air passes through the outside coil. Some water vapor present within the inside air condenses on the inside coil. This water slides to the bottom of that coil, then falls into a "drip pan" located beneath the coil. A small drainage pipe carries the liquid water out of the indoor unit and routes it to a suitable drain.

Air-to-air heat pumps are currently more common in North America because of the high percentage of homes that:

A) Require cooling
B) Have forced-air distribution systems
for all HVAC functions

Although common, air-to-air heat pumps do have limitations. Their COP and heating capacity is strongly affected by outdoor temperature. In the heating mode, the cooler the outdoor air, the lower the heating capacity of the heat pump. When the heat pump can no longer keep up with the rate of building heat loss, the electric resistance strip heat is typically turned on. Although simple and reliable, electric resistance strip heaters are significantly more expensive to operate, per unit of heat delivery, compared to heat gathered using the refrigeration cycle of the heat pump.

Although technology is improving, many air-to-air heat pumps are still not suitable for severe winter climates where temperatures frequently drop below 0ºF and large accumulations of snow and ice are possible around the outdoor unit.

Figure 1-5

The presence of an outside unit as shown in Figure 1-5 is also aesthetically objectionable to some owners. The sounds created by the outdoor unit, although often tolerated, are certainly not appreciated. The outdoor unit must also be kept free of debris such as grass, leaves and insect nests. Finally, mechanical components that are directly exposed to the elements do not last as long as equipment that is protected within a building.

AIR-TO-WATER HEAT PUMPS

Air-to-water heat pumps use an outside unit similar to that of an air-to-air heat pump. However, the heat generated while operating in the heating mode is delivered to a hydronic distribution system within the building. The use of a hydronic distribution system allows for many options that are not possible with forced-air distribution systems. Many are discussed in later sections.

Figure 1-6 shows the outside unit of a modern air-to-water heat pump. The insulated pipes connecting to the interior portion of the system are seen penetrating the wall.

Figure 1-6

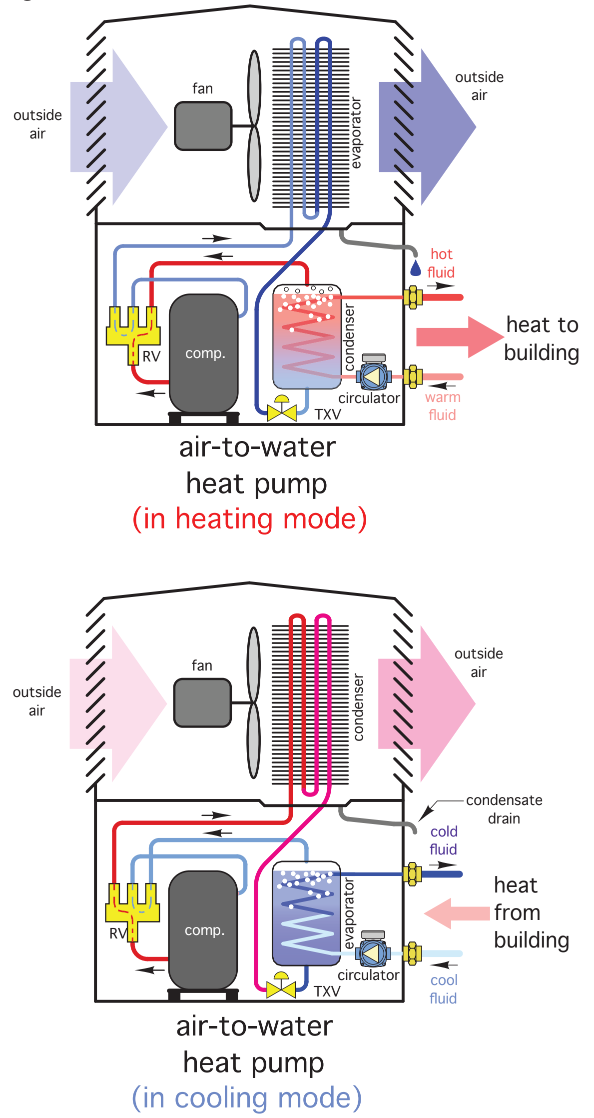
Figure 1-7 shows the major internal components in a "self-contained" reversible air-to-water heat pump.

In colder climates, an antifreeze solution is circulated between the outside unit and indoor load. This reduces the risk of freezing during a power outage or if the heat pump becomes inoperable during cold weather. The antifreeze solution can be directly circulated through the indoor distribution system or separated from a water-based hydronic distribution system using a heat exchanger, as shown in Figure 1-8.

Other types of air-to-water heat pumps use a "split" refrigeration system like that of an air-to-air heat pump. A set of refrigerant tubes connects the outdoor unit with the indoor unit. Such units eliminate any water or water-based antifreeze fluids in the outdoor unit, and thus are not prone to freezing, even if not operating. However, split systems require proper installation and charging of refrigerant line sets, and thus require an installation technician trained and equipped for such work.

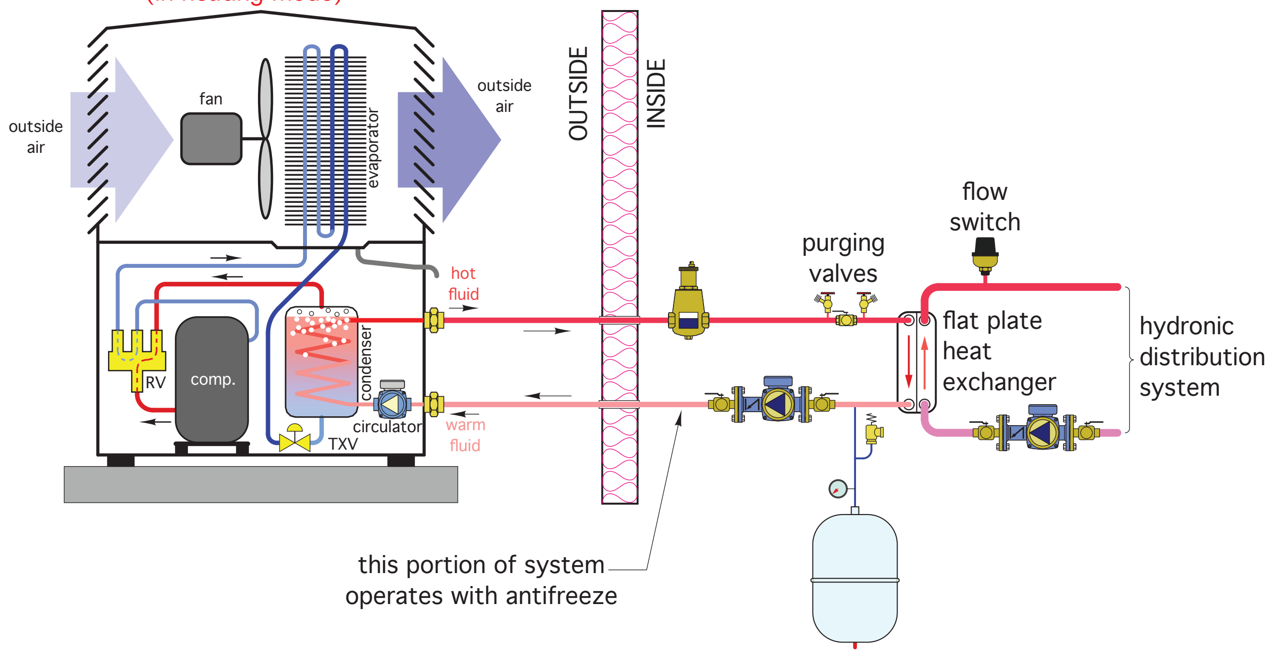
As with air-to-air heat pumps, most air-to-water heat pumps are reversible. As such, they are capable of producing chilled water for building cooling or other processes requiring chilled water. Later sections discuss how to apply air-to-water heat pumps for hydronic cooling applications.

Figure 1-7



Some non-reversible air-to-water heat pumps are also used for dedicated domestic water heating applications.

Figure 1-8



WATER-TO-AIR HEAT PUMPS

A "water-source" heat pump is used in nearly all applications where low-temperature heat is to be extracted from a media other than air. The fluid conveying the low-temperature heat to the heat pump can be water or a water-based antifreeze solution, and it can come from a variety of sources

Figure 1-9

Courtesy of GeoSystems LLC

The most common type of water-source heat pump is the water-to-air heat pump. In the heating mode, it uses a water-to-refrigerant heat exchanger as its evaporator. Heat output is delivered to a stream of air drawn through the condenser coil and forced through a duct system by the heat pump's blower.

Figure 1-9 shows an example of a water-to-air heat pump configured as a vertical cabinet unit. Return air enters the upper left side of the cabinet, passes through a filter and then through the refrigerant-to-air heat exchanger. The conditioned air is then drawn through the blower and discharged vertically from the cabinet into a duct system. The compressor and other electrical or refrigeration system components are located in the lower portion of the cabinet.

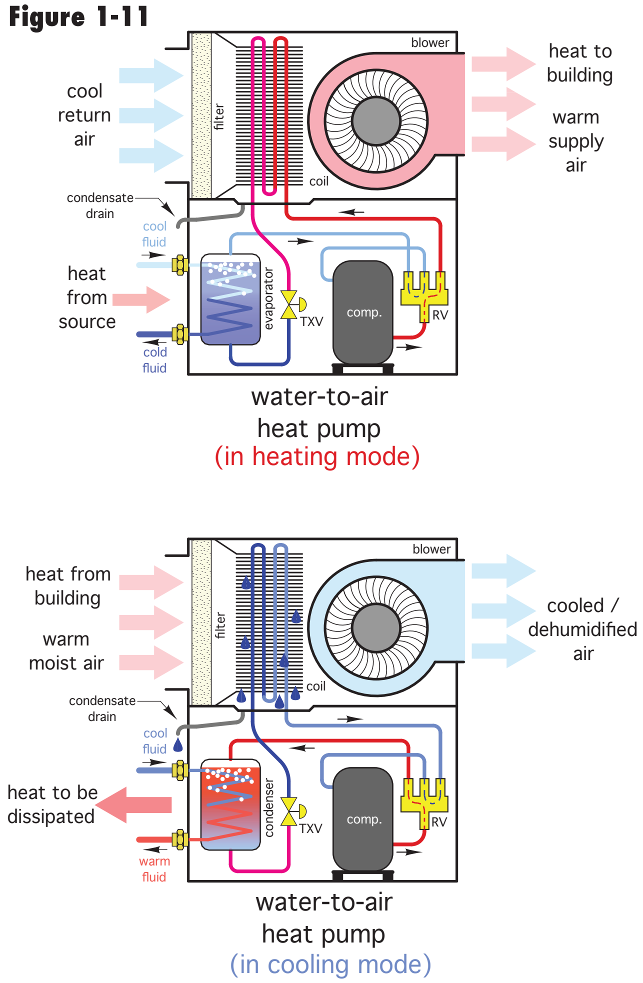
Water-to-air heat pumps are also available with horizontal cabinets, as shown in Figure 1-10. Such units contain essentially the same hardware as a vertical cabinet unit, but they are designed for installation above a suspended ceiling or other space where a low height is required.

Figure 1-10

Courtesy of ClimateMaster

The internal components of a reversible water-to-air heat pump are shown in Figure 1-11. As previously discussed, the reversing valve effectively swaps the functions of evaporator and condenser depending on the operating mode.

Figure 1-11



WATER-TO-WATER HEAT PUMPS

One of the most opportune situations for a heat pump is when low-temperature heat can be extracted from a stream of water and higher-temperature heat can be dissipated into another stream of water. Heat pumps configured for such situations are called "water-to-water" heat pumps. They can be used in a wide variety of applications for building heating and cooling, as well as applications such as domestic water heating, pool heating or processes where either heated water, chilled water or both are required. The majority of the hydronic heating and cooling applications described in later sections will use water-to-water heat pumps.

Figure 1-12 shows an example of a modern water-to-water heat pump. In this case, all piping connections for the water streams supplying the evaporator and condenser are made on the right front side of the cabinet. The unit shown has additional piping connections for domestic water heating.

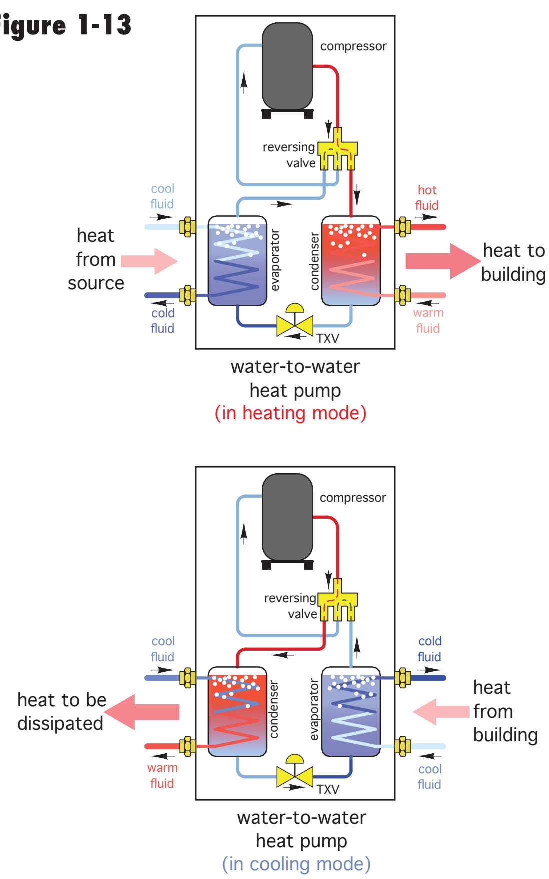
Figure 1-12

Courtesy of ClimateMaster

The internal components of a reversible water-to-water heat pump are shown in Figure 1-13. As with the previously described heat pumps, the reversing valve effectively swaps the functions of evaporator and condenser depending on the operating mode.

Most the heat pumps described in this section are "on/off" rather than modulating devices. When on, they must have proper flow of the source media, as well as the load media. A common range of flow rate for water-to-refrigerant heat exchangers is 2 to 3 gallons per minute of water flow per ton (e.g., per 12,000 Btu/hr) of heat transfer. Anything that restricts this flow will eventually create conditions that automatically shut off the heat pump's compressor to avoid serious damage. Such conditions must be avoided through proper system design. Later sections describe how to do this while creating systems that are stable, efficient and able to provide many years of service.

Figure 1-13



2. THERMAL PERFORMANCE OF HEAT PUMPS

There are two indices that describe the heating performance of any heat pump. They are:

- Heating capacity
- Coefficient of performance (COP)

Similarly, there are two indices that describe the cooling performance of heat pumps:

- Cooling capacity
- Energy efficiency ratio (EER)

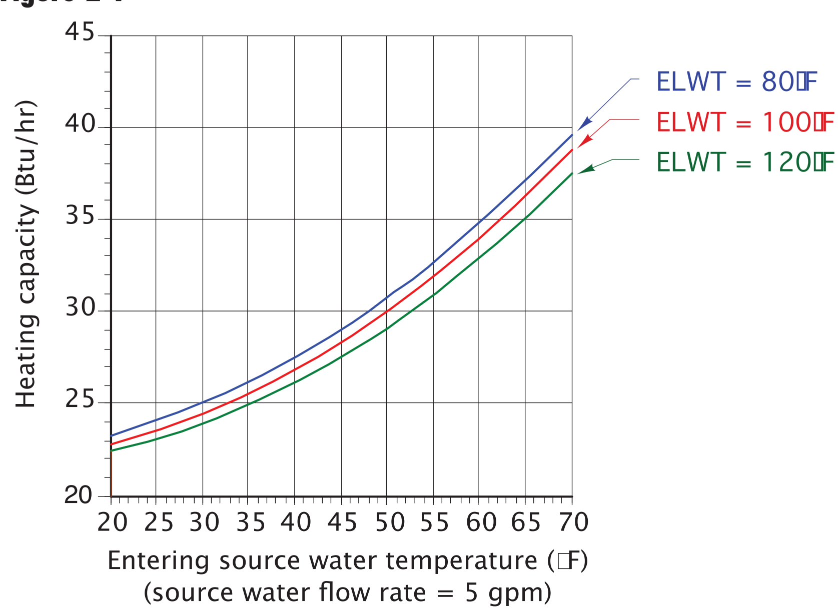
Each of these performance indices will be discussed in the context of a water-to-water heat pump. The performance trends shown will also hold true for other types of heat pumps.

HEATING CAPACITY

The heating capacity of a heat pump is the rate at which it delivers heat to the load. As such, it is similar to the heating capacity of a boiler. However, *the heating capacity of any heat pump is highly dependent on its operating conditions, specifically the temperature of the source media and the temperature of the load media.* Heating capacity also depends on the flow rate of both the source and load media through the heat exchangers that serve as the heat pump's evaporator and condenser.

Figure 2-1 shows heating capacity information for a modern water-to-water heat pump.

Figure 2-1



The heating capacity is plotted as a function of entering source water temperature, and three different entering load water temperatures (ELWT). The entering source water temperature is that of the water, or water/antifreeze solution entering the heat pump's evaporator. Likewise, the entering load water temperature is that of the water entering the heat pump's condenser.

This graph shows that heating capacity drops off significantly with decreasing source water temperature. This relationship is crucially important in applications where source water temperature varies over a wide range. For example, during the month of October, the fluid temperature entering the evaporator of a water-to-water heat pump connected to a horizontal earth loop might be 60ºF. In such a case, the heating capacity of the heat pump represented in Figure 2-1 would be approximately 35,000 Btu/hr (assuming the corresponding entering load water temperature was 80ºF). However, by early March, the fluid temperature supplied by the same horizontal earth loop might only be 35ºF. This would reduce the heating capacity of the heat pump to around 26,000 Btu/hr (assuming the same entering load water temperature). This 26% drop in heating capacity is significant and must be accommodated through compatible selection of the heat emitters and distribution system.

Heating capacity is also affected by the entering *load* water temperature. The higher this temperature, the lower the heating capacity of the heat pump. Figure 2-1 shows three representative entering load water temperatures: 80º, 100º, and 120ºF. Although the drop in heating capacity per degree Fahrenheit change in load water temperature is not as pronounced as it is with decreasing source water temperature, it still must be recognized during system design. *Hydronic heating distribution systems that operate at low water temperatures are always preferred from the standpoint of heat pump performance.*

The temperature of the water *leaving* the heat pump depends on water flow rate and the current heating capacity. It can be determined using Formula 2-1.

Formula 2-1

$$T_{LLWT} = T_{ELWT} + \frac{Q_{hp}}{495 \times f_c}$$

Where:
T_{LLWT} = temperature of the load water leaving heat pump (ºF)
T_{ELWT} = temperature of load water entering heat pump (ºF)
Q_{hp} = current heating capacity of heat pump (BTU/hr)
f_C = water flow rate through heat pump condenser (gpm)
495 = a constant based on water

For example: If the heat pump represented by Figure 2-1 is operating with 80ºF entering load water temperature and 35ºF entering source water temperature, its heating capacity is 26,000 Btu/hr. Assuming a flow rate of 8 gallons per minute through the condenser, the leaving load water temperature would be:

$$T_{LLWT} = T_{ELWT} + \frac{Q_{hp}}{495 \times f_c} = 80 + \frac{26,000}{495 \times 8} = 86.6^\circ F$$

The flow rate through both the evaporator and condenser also affect the heat pump's heating capacity. Figure 2-2 shows this effect for a water-to-water heat pump operating at a source water flow rate of 9 gallons per minute and 5 gallons per minute.

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 in both the evaporator and condenser. This, in turn, reduces the rate of heat transfer.

It is customary to describe the heating and cooling capacity of refrigeration-based equipment such as heat pumps using the units of "tons." In this context, a ton describes a *rate* of heat flow—specifically, 1 ton equals 12,000 Btu/hr. Thus, a "3-ton" heat pump implies it has a nominal heating or cooling capacity of 3 x 12,000 or 36,000 Btu/hr. In this context, the "tonnage" of a heat pump has nothing to do with heat pump's weight. Keep in mind that a description of a heat pump based on tons is a *nominal* rating at some specific set of operating conditions. Thus, a "3-ton" rated heat pump could produce a heat output significantly higher than 3 tons when operated under more favorable conditions, and significantly less than 3 tons when operated under less favorable conditions.

COEFFICIENT OF PERFORMANCE (COP)

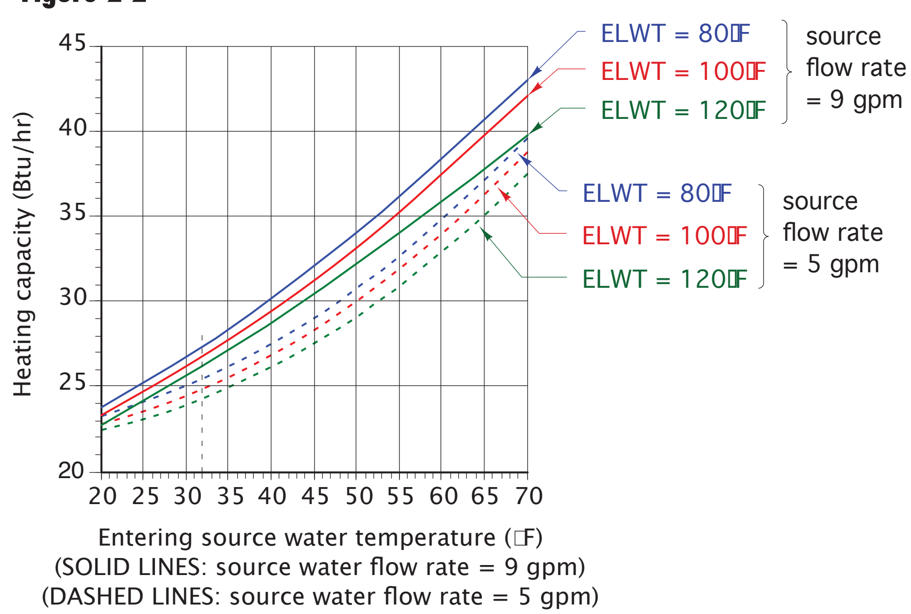
The coefficient of performance of a heat pump is a number that describes the efficiency of the overall process of extracting low-temperature heat and converting it into higher-temperature heat.

The term efficiency always relates a desired output to a necessary input. In the case of a boiler, the desired output is the rate of heat transfer to the water passing through the boiler. The necessary input is the rate at which the boiler consumes fuel. The efficiency of this process is expressed as a *ratio* of the desired output divided by the necessary input. This ratio is given as Formula 2-2.

Formula 2-2

$$\text{efficiency} = \frac{\text{desired output}}{\text{necessary input}}$$

Figure 2-2



For efficiency to be expressed as a decimal percentage, the units of "desired output" must be the same as those of the "necessary input."

In the case of a heat pump, the desired output is the rate at which heat is transferred to the load. The necessary input is the rate of electrical energy used to operate the heat pump. The ratio of these two quantities, expressed in the same units, is called the Coefficient Of Performance (COP) of the heat pump and is given in Formula 2-3.

Formula 2-3

$$COP = \frac{\text{heat output (Btu/hr)}}{\text{electrical input (watt)} \times 3.413}$$

does not include the low-temperature heat input. The latter is assumed to be "free" heat. Thus the definition of COP reflects only the "paid for" electrical input power as the necessary input.

The ultimate thermal performance objective for any heat pump is to maximize the COP. The higher the COP, the greater the heat output rate for a given rate of electrical energy input.

The following example shows how to calculate the COP of a heat pump based on its current operating conditions. Assume that a water-to-water heat pump is delivering heat to a load at a rate of 37,000 Btu/hr. The electrical power to operate the heat pump is measured as 3,000 watts. The COP of this heat pump under its current operating conditions is:

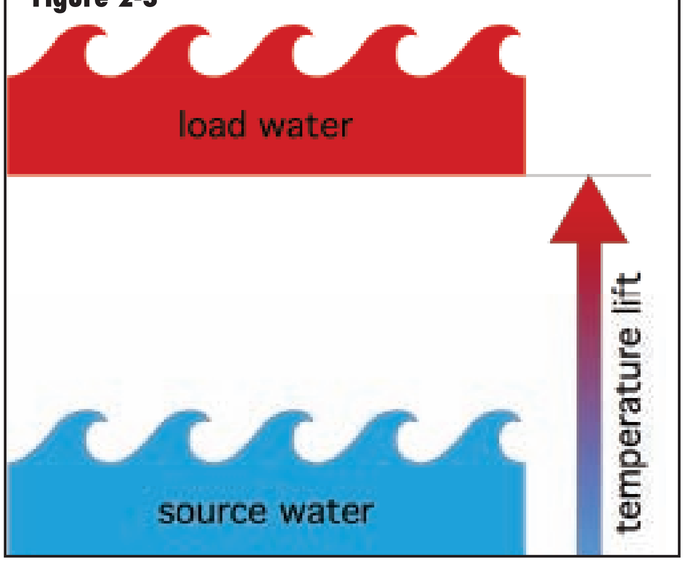
$$COP = \frac{\text{heat output (Btu/hr)}}{\text{electrical input (watt)} \times 3.413} = \frac{37{,}000\text{Btu/hr}}{3000\text{watt} \times 3.413\left(\frac{\text{Btu/hr}}{\text{watt}}\right)} = 3.61$$

Notice that the units of watt and Btu/hr both cancel out in this formula. The COP is thus 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 energy input. Thus, if the COP of a heat pump is 3.61, it provides 3.61 units of heat output per unit of electrical energy input.

An alternative way to think of COP is to multiply it by 100 and use that number as a comparison to the efficiency of an electric resistance heating device. For example, if an electric resistance space heater is 100% efficient, then by comparison, a heat pump with a COP of 3.61 would be 361% efficient.

Figure 2-3



As is true with heating capacity, the COP of a heat pump is very dependent on the operating conditions (e.g., the temperature of the source media, as well as the media to which the heat pump outputs heat). The closer the temperature of the source media is to the temperature of the load media, the higher the heat pump's COP.

One can visualize the difference between these temperatures as the "temperature lift" of the heat that the heat pump must provide, as shown in Figure 2-3. The smaller the lift, the higher the COP.

The theoretical maximum COP that any heat pump can attain was established by 19th century scientist Sadi Carnot. It is based on the *absolute* temperatures of the source media and load media, and is given in Formula 2-4.

Formula 2-4

$$COP_{max} = \frac{T_{load}}{(T_{load} - T_{source})}$$

Where:

T_{load} = *absolute* temperature of the load media to which heat is delivered (ºR)

T_{source} = *absolute* temperature of the source media from which heat is extracted (ºR)

ºR = ºF + 458º

Thus, the maximum possible COP of a heat pump extracting heat from lake water at 40ºF and delivering that heat to a stream of load water entering the heat pump at 100ºF would be determined by first converting these temperatures to degrees Rankine, and then using Formula 2-4.

100 ºF + 458 º = 558 ºF
40 ºF + 458 º = 498 ºF

$$COP_{max} = \frac{T_{load}}{(T_{load} - T_{source})} = \frac{558^\circ R}{(558^\circ R - 498^\circ R)} = 9.3$$

This theoretical COP is based on a hypothetical heat pump that has no mechanical energy losses due to friction or electrical losses due to resistance. It is also based on an "infinitely sized" source and loads that remain at the same temperature as they exchange heat.

No real heat pump operates under such idealized conditions, and thus no real heat pump ever attains the Carnot COP. Still, the Carnot COP provides a means

Figure 2-4

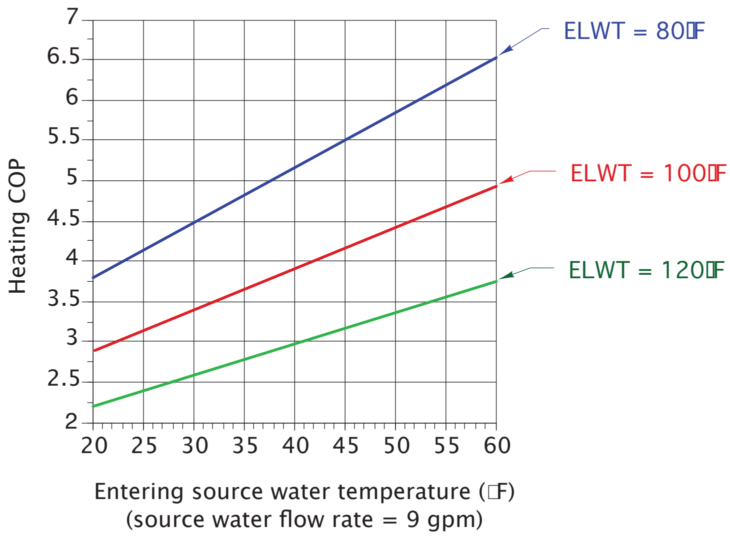
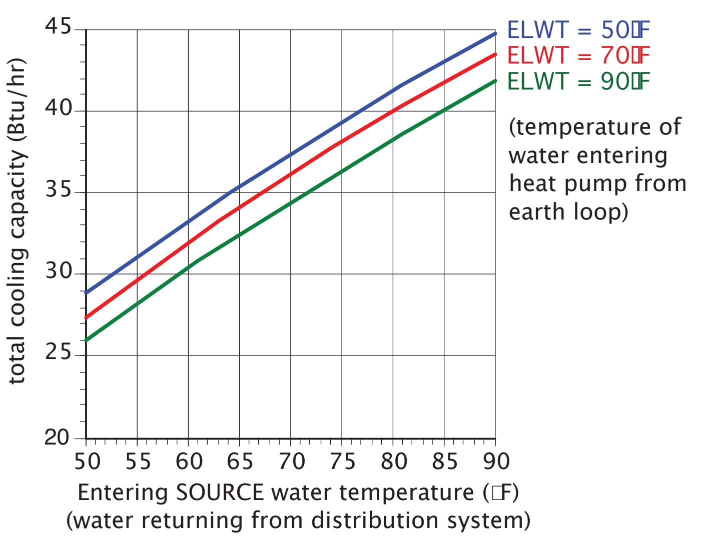


Figure 2-5



of comparing the performance of evolving heat pump technology to a theoretical limit. It also demonstrates the inverse relationship between the "temperature lift" of a heat pump and COP. Notice that the theoretical Carnot COP of a heat pump, calculated using Formula 2-4, approaches infinity as the temperature lift (T_{high}-T_{low}) approaches zero.

The COP of a modern heat pump is substantially lower than the Carnot COP and very dependent on the temperature of both the source and load media. Figure 2-4 shows this dependence for a typical residential size water-to-water heat pump.

Notice 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 source as high as possible, while also 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 heat pump with a hydronic distribution system.

COOLING PERFORMANCE OF HEAT PUMPS

The thermal performance of a heat pump used to provide cooling is given by two indices:

- Cooling capacity
- Energy Efficiency Ratio (EER)

Cooling capacity represents the *total* cooling effect (sensible cooling plus 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 typical water-to-water heat pump with a nominal cooling capacity of 3 tons is represented graphically in Figure 2-5. The horizontal axis shows entering source water temperature. This is the temperature of the water returning from the cooling distribution system, and flowing into the heat pump's evaporator. The three sloping curves on the graph represent three entering loop water temperatures. This is the temperature of the fluid stream that the heat is being dissipated to. For example, the blue line showing an ELWT of 50ºF could represent fluid returning from an earth loop and entering the heat pump at 50ºF.

As the temperature of the entering source water goes up, so does the heat pump's cooling capacity. Thus the heat pump yields a higher cooling capacity when receiving water from the return side of the distribution system at 60ºF compared to 50ºF. It can also be seen that as the temperature of the fluid into which heat is dissipated increases, the heat pump's cooling capacity decreases.

ENERGY EFFICIENCY RATIO

In North America, the common way of expressing the instantaneous cooling efficiency of a heat pump is an index called EER (Energy Efficiency Ratio), which is defined as follows:

$$EER = \frac{Q_c}{w_e} = \frac{\text{cooling capacity (Btu/hr)}}{\text{electrical input wattage}}$$

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 electrical power required to produce a given rate of cooling.

Like COP, the EER of a water-to-water heat pump is a function of the entering source water temperature, and the entering earth loop water temperature. This variation is shown in Figure 2-6.

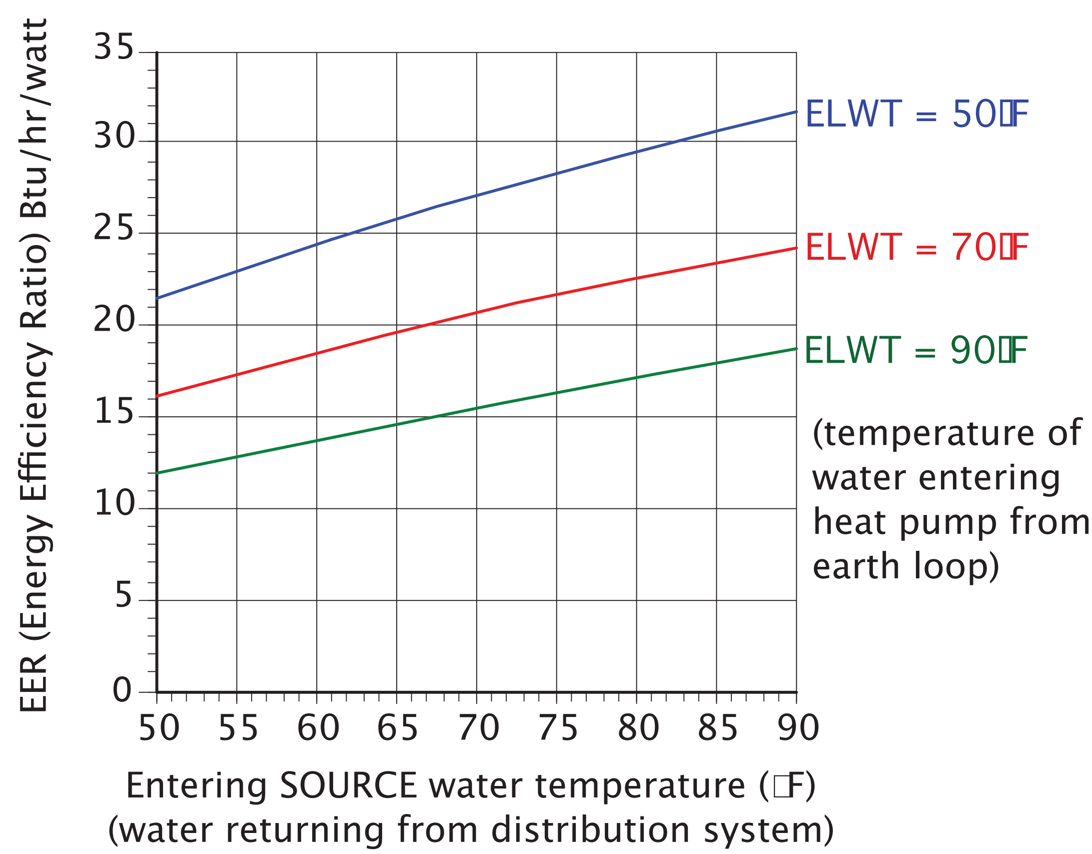
This graph shows that EER increases as the temperature of the entering source water increases. However, higher entering source water temperature also reduces the cooling capacity of the distribution system.

It can also be seen that the lower the entering loop water temperature, the higher the EER.

As is true with heating, design decisions that reduce the temperature difference between the entering source water and entering loop water will improve the cooling capacity and EER of the heat pump.

Higher fluid flow rates through the evaporator, the condenser, or both, will also increase cooling capacity and EER. However, increased flow typically requires higher electrical power input to the circulator(s) creating this flow. Flow rates higher than 3 gallons per minute per ton of cooling capacity are not necessary or desirable.

Figure 2-6



3. GEOTHERMAL HEAT PUMPS

The ideal "free" heat source for any heat pump used to heat buildings would remain as warm as possible during the heating season. The ideal heat "sink" to which unwanted building heat could be rejected would remain as cool as possible during warm weather.

In most areas of the United States, the temperature of outside air varies considerably between the heating and cooling seasons. For example, in Atlanta, GA, the 99% winter design dry bulb temperature is 23ºF and the summer design dry bulb temperature is 92 ºF. In more extreme Northern climates, this deviation can be even larger. For example, in Bismarck, ND, there is a difference of 116ºF between the winter and summer design dry bulb temperatures.

Such large variations in outdoor air temperature strain the ability of air-source heat pumps, especially during temperature extremes. Prolonged cold weather can cause such heat pumps to operate at relatively low COPs and correspondingly low heating capacities. The latter often means that higher-cost electric resistance heating will be required to supplement the output of the heat pump. Likewise, high air temperatures reduce the cooling capacity and EER of air source heat pumps.

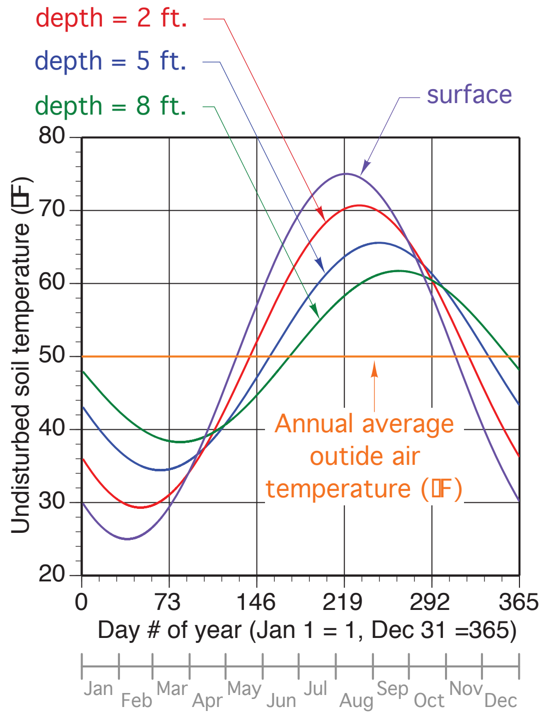
Figure 3-1

HEAT FROM THE EARTH

It has long been recognized that the temperature of the soil in any given location fluctuates less than that of outside air. Soil within a few feet of the surface acts as a seasonal storage media for solar energy. It absorbs heat from late spring through summer and slowly allows that heat to dissipate during later fall and winter. This effect significantly reduces the variation between the highest and lowest soil temperature over a year, compared to the temperature variation in outside air.

The magnitude of the soil temperature variation decreases with depth below the surface, as seen in Figure 3-2.

Figure 3-2



The curves in Figure 3-2 are based on a typical meteorological year in Albany, NY. In this location, the annual average outside air temperature is approximately 50ºF.

The soil temperature varies above and below the annual average air temperature at a given location. The greater the depth below the surface, the less the variation. Figure 3-2 also shows that depth delays the occurrence of the minimum and maximum soil temperature relative to when the statistically average minimum and maximum outside air temperatures occur. For example, the maximum soil temperature at a depth of 8 feet below the surface occurs in late September, several weeks later than the average maximum air temperature. Likewise, the minimum soil temperature at the 8-foot depth occurs in late March—

again, several weeks later than the minimum outside air temperature.

The thermal conductivity and moisture content of the soil also affect its temperature at a given depth and time of year.

These time shifts between outdoor temperature and soil temperature, in combination with the vast thermal mass of soils in the proximity to buildings, make heat stored in soil an attractive and fully renewable heat source for a water-source heat pump. They also create a preferable heat sink for water-source heat pumps that provide building cooling.

The use of the soil as a heat source for heat pumps is not new. The first patent on this concept was issued in Switzerland in 1912. Within the United States, the Edison Electric Institute experimented with geothermal heat pumps during the 1940s and ’50s.

One of the biggest challenges was creating a buried piping loop that was easy to install and would last for many decades. Early attempts using metal and PCV tubing often ended with leaking pipes buried several feet deep. Such failures, in combination with relatively low fuel costs during this time, discouraged wider implementation of geothermal heat pumps.

During the 1970s, development of heat-fusible, high-density polyethylene (HDPE) piping, along with efficient trenching and drilling methods, provided the critical link for constructing reliable and easily installed earth loop heat exchangers. Design and installation methods were pioneered by researchers at Oklahoma State University, and others, over the last 30 years.

Today, high-cost energy, the use of reliable HDPE and PEX tubing for earth loops, and the availability of accurate design procedures have lead to rapid growth in the geothermal heat pump market across North America and other developed countries. Such systems can take many forms depending on the site conditions, local electric utility rates, the heating and cooling needs of the building, and the type of distribution used in the building.

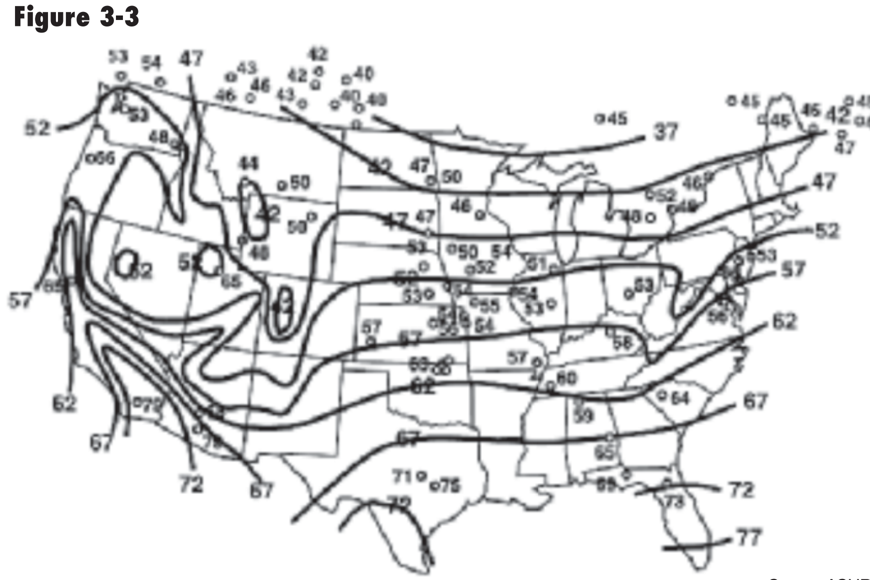
Nearly all geothermal heat pump systems can be enhanced through modern hydronics technology. Techniques such as hydraulic separation, manifold-based distribution systems, zoning, thermal storage and variable-speed circulators can all be successfully applied in combination with geothermal heat pumps. This issue of idronics discusses several systems that leverage the advantages of modern hydronics technology to enhance the high thermal efficiency of geothermal heat pump systems.

OPEN-LOOP SYSTEMS

In most areas of North America, the temperature of ground water is within the operating range of water-to-air and water-to-water heat pumps. This is also true for water in large ponds or lakes, even those that completely freeze over in winter. The liquid water near the bottom of frozen lakes and ponds has a temperature of about 4ºC (39.2ºF). Water attains its maximum density at this temperature, and thus settles to the bottom of the lakes and ponds.

The temperature of ground water in wells that are at least 25 feet deep only varies a few degrees Fahrenheit during the year. At these depths, the solar gains of summer have very little influence in raising ground water temperature.

Figure 3-3



Source ASHRAE

Likewise, the extreme cold temperatures of winter have very little influence on lowering ground water temperature. Thus, *ground water temperature in most drilled wells remains close to the average annual outside air temperature.* Figure 3-3 gives the approximate ground water temperature for locations within the continental US.

Two key issues must be examined whenever ground water or water from a lake or pond is being considered for use with a water-source heat pump:

- Water *quantity*
- Water *quality*

WATER QUANTITY

Water *quantity* implies that the source must be capable of *sustaining* the flow rate required by the heat pump—24 hours per day if necessary. A conservative estimate of water usage is 3 gallons per minute per ton (12,000 Btu/hr) of heat transfer at the evaporator or condenser. The latter will be different depending on whether the heat pump is operating in the heating or cooling mode. In the heating mode, the rate of heat absorption from a ground water stream flowing through the evaporator can be calculated using Formula 3-1.

Formula 3-1

$$Q_{evap} = Q_{load}\left(\frac{COP-1}{COP}\right)$$

Where:

Q_{evap} = rate of heat absorption from ground water by the heat pump's evaporator (Btu/hr)

Q_{load} = rate of heat delivery from heat pump's condenser to heating load (Btu/hr)

COP = coefficient of performance of the heat pump

Example: A water-source heat pump is operating at a COP of 3.61 while delivering heat to its load at 38,000 Btu/hr. Determine the required water flow rate through the evaporator assuming 3 gpm/ton.

Solution: The rate of heat absorption at the evaporator is:

$$Q_{evap} = Q_{load}\left(\frac{COP-1}{COP}\right) = 38,000\left(\frac{3.61-1}{3.61}\right) = 27,470\,Btu/hr$$

The required water flow rate is:

$$\left(\frac{27,470\,Btu/hr}{12000\,\frac{Btu/hr}{ton}}\right)\left(\frac{3gpm}{ton}\right) = 6.87\,gpm$$

Although this may not seem like a large flow rate, it equates to 6.87 x 60 = 412 gallons per hour, or 412 x 24 = 9,888 gallons per day, if the heat pump remains in continuous operation. Most large ponds or lakes could easily supply a nominal 10,000 gallons per day—assuming the water returns to the pond or lake after passing through the heat pump. However, many residential wells could *NOT* supply this quantity of water, especially on a sustained basis. In some installation, heat pumps sourced from residential wells have exceeded the well's ability to supply water. This not only causes the heat pump to automatically shut down, it may also leave the building without a source of fresh water—if the latter was supplied from the same well.

When operating in the cooling mode, the rate of heat rejection to the ground water stream is based on the total heat output of the heat pump (e.g., heat absorbed by the evaporator plus the heat generated by the compressor). Again, a conservative estimate of 3 gpm per ton of heat rejection can be used to determine total water requirements.

Some water-source heat pumps can operate on as little as 2 gallons per minute per ton of heat transfer. However, the minimum acceptable water flow rate should always be verified with the heat pump manufacturer when planning a water supply system.

After water has passed through a heat pump, it must be properly returned to the environment. If extracted from a lake or pond, it is likely that it can be returned to that same body of water. However, increasing environmental regulations may constrain such situations. Always check on local and state environmental codes before planning such systems.

Water extracted from a well may require a more elaborate means of disposal. Although the water is not contaminated as it passes through the polymer tubing and copper or stainless steel piping components of the system, do not simply assume it can be disposed of at a ditch, storm sewer or dry well. Most states now have regulations regarding if, when and how water can be returned to an underground aquifer. Again, be sure to investigate the options based on local and state regulations.

In localities where water can be re-injected into the ground it may be necessary to drill a separate re-injection well within a prescribed distance from the source well. In other cases, it may be possible to re-inject the water into the same well that supplied it. The latter is more common with deep wells. Detailed evaluation of such options is best done by design professionals familiar with local regulations and subsurface conditions. Local well drillers are often a good place to start when investigating options and related costs.

WATER QUALITY

The other important issue regarding use of ground water with heat pumps is water *quality*. More specifically, exactly what, if anything, is in the ground water? Ground water that contains, silt, calcium carbonate, sulfur compounds, salt, iron, bacteria or other contaminants can quickly create deposits within the water-to-refrigerant heat exchanger of a water-source heat pump. This will cause a rapid drop in heat transfer and may even completely plug the heat exchanger. Such conditions must be avoided.

The table in Figure 3-4 lists the water quality standards recommended by one manufacturer of water-source heat pumps. Other manufacturers may differ in their minimum recommended standards for ground water. When an open-loop system is being planned, *always* reference the water quality standards required by the heat pump manufacturer, and *always* have the water at the site professionally tested to determine if it meets or exceeds these standards. Failure to do so could render an otherwise well-planned system virtually useless.

Assuming that the ground water on-site meets both the quantity and quality standards, the balance of the system must be designed to provide proper flow from the ground water source through the heat pump, and then allow proper return of that water to the environment.

In situations where the ground water is supplied from a well, it is common to use a submersible pump to provide flow and lift. The latter must be evaluated in situations where the water table may be many feet below the

Figure 3-4: Water Quality Standards

Water Quality Parameter	HX Material	Closed Recirculating	Open Loop and Recirculating Well		
Scaling Potential - Primary Measurement					
Above the given limits, scaling is likely to occur. Scaling indexes should be calculated using the limits below					
pH/Calcium Hardness Method	All	-	**pH < 7.5 and Ca Hardness <100ppm**		
Index Limits for Probable Scaling Situations - (Operation outside these limits is not recommended)					
Scaling indexes should be calculated at 150°F [66°C] for direct use and HWG applications, and at 90°F [32°C] for indirect HX use. A monitoring plan should be implemented.					
Ryznar Stability Index	All	-	**6.0 - 7.5** If >7.5 minimize steel pipe use.		
Langelier Saturation Index	All	-	**-0.5 to +0.5** If <-0.5 minimize steel pipe use. Based upon 150°F [66°C] HWG and Direct well, 85°F [29°C] Indirect Well HX		
Iron Fouling					
Iron Fe^{2+} (Ferrous) (Bacterial Iron potential)	All	-	**<0.2 ppm (Ferrous)** If Fe^{2+} (ferrous)>0.2 ppm with pH 6 - 8, O2<5 ppm check for iron bacteria		
Iron Fouling	All	-	**<0.5 ppm of Oxygen** Above this level deposition will occur.		
Corrosion Prevention					
pH	All	**6 - 8.5** Monitor/treat as needed	**6 - 8.5** Minimize steel pipe below 7 and no open tanks with pH <8		
Hydrogen Sulfide (H_2S)	All	-	**<0.5 ppm** At H_2S>0.2 ppm, avoid use of copper and copper nickel piping or HX's. Rotten egg smell appears at 0.5 ppm level. Copper alloy (bronze or brass) cast components are OK to <0.5 ppm.		
Ammonia ion as hydroxide, chloride, nitrate and sulfate compounds	All	-	**<0.5 ppm**		
Maximum Chloride Levels			Maximum Allowable at maximum water temperature.		
			50°F (10°C)	75°F (24°C)	100°F (38°C)
	Copper	-	<20ppm	NR	NR
	CuproNickel	-	<150 ppm	NR	NR
	304 SS	-	<400 ppm	<250 ppm	<150 ppm
	316 SS	-	<1000 ppm	<550 ppm	< 375 ppm
	Titanium	-	>1000 ppm	>550 ppm	>375 ppm
Erosion and Clogging					
Particulate Size and Erosion	All	<10 ppm of particles and a maximum velocity of 6 fps [1.8 m/s] Filtered for maximum 800 micron [800mm, 20 mesh] size.	<10 ppm (<1 ppm "sandfree" for reinjection) of particlesand a maximum velocity of 6 fps [1.8 m/s]. Filtered for maximum 800 micron [800mm, 20 mesh] size.Any particulate that is not removed can potentially clog components.		

Rev.: 01/21/09B

Notes:
- Closed Recirculating system is identified by a closed pressurized piping system.
- Recirculating open wells should observe the open recirculating design considerations.
- NR - Application not recommended.
- "-" No design Maximum.

Courtesy of ClimateMaster

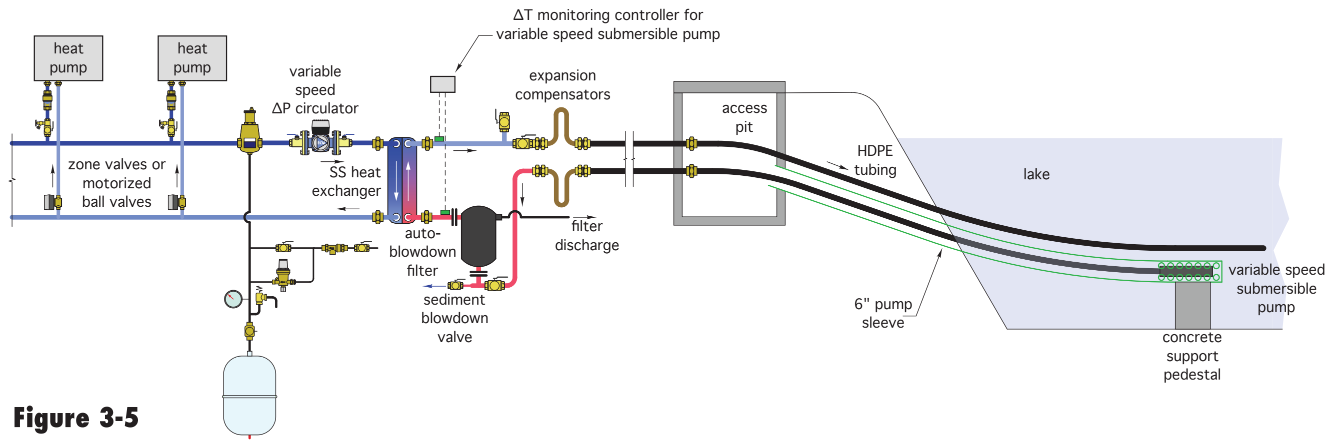


Figure 3-5

surface. Under such conditions, the pump must be sized to lift the water, as well as overcome the frictional head losses of the supply piping, heat pump heat exchanger and return piping. When large lifts are required, the operating cost of the pump may significantly detract from the thermal efficiency of the heat pump.

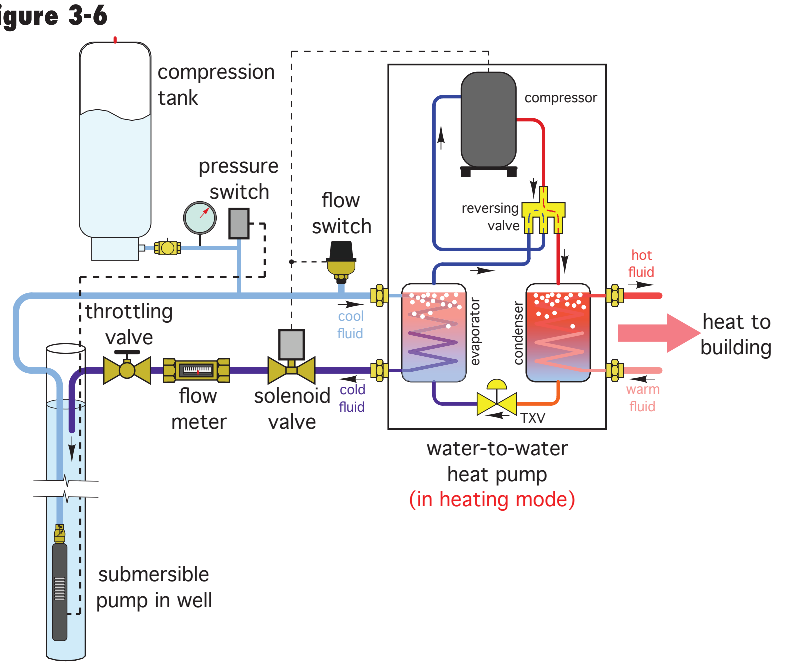
Figure 3-5 shows a representative situation in which water is being supplied by a submersible pump within a lake. The pump is mounted on a pedestal to keep it above the silt layer in the lake. The pump, along with attached piping and wiring, has been pushed into position through a 6-inch diameter PVC sleeve with holes at the end. This allows the pump to be pulled back to shore for maintenance when necessary. The shore end of the sleeve terminates within a concrete vault large enough to allow the piping to bend up and out of the access hole. This vault also provides a location to connect piping and wiring. The upper portions of the vault can be covered with extruded polystyrene insulation to minimize heat loss. The vault should be located in well-drained soil and be as watertight as possible. A floor drain or drainage sump with pump is also recommended to minimize any water accumulation within the vault.

The submersible pump is operated by a variable-speed controller that monitors the temperature differential across the heat exchanger. The goal is to maintain a preset temperature drop. An increasing temperature differential across the heat exchanger implies an increasing thermal load. In response, the speed of the submersible pump is increased as necessary to restore the desired temperature differential. If the temperature differential decreases, the speed of the submersible pump decreases to lower power consumption under reduced load.

Flow through each heat pump is controlled by a zone valve, or motorized ball valve, that opens only when its associated heat pump is operating. A variable-speed pressure-regulated circulator modulates the flow rate to the heat pumps based on the status of these valves. This "demand-based" flow control lowers pumping power under partial load conditions.

Another type of open-loop heat pump system is shown in Figure 3-6. It draws source water directly from a drilled well. After passing through the heat pump, this water is returned to the same well. In some cases, the well may also supply potable water to the building.

Figure 3-6



The submersible pump is operated by a pressure switch that monitors pressure within the compression tank. The pressure switch turns on the pump when the pressure in the tank drops to or below a lower threshold value. It turns the pump off when pressure is restored to an upper limit. The compression tank should be sized and pre-pressurized so that the pump remains off for a minimum of 3 minutes, or as otherwise recommended by the pump manufacturer.

Water flow through the heat pump is controlled by an electrically operated solenoid valve. This valve is located downstream of the heat pump. It opens whenever the heat pump is operating, and closes when the heat pump shuts off.

Other components in the piping include a flow meter, throttling valve and flow switch. The throttling valve, in combination with the flow meter, allows the water flow rate to be adjusted to the target value required by the heat pump. This flow will vary somewhat depending on the working pressure range of the compression tank and pressure switch. The flow switch verifies that suitable water flow exists before the heat pump is allowed to operate.

The throttling valve also suppresses cavitation within the solenoid valve by keeping the pressure in the return piping above the vapor pressure of the water. This is especially important if there is a large vertical distance between the water level in the well and the heat pump.

CLOSED-LOOP GEOTHERMAL HEAT PUMP SYSTEMS

Not all sites lend themselves to the requirements for open-loop heat pump systems. Even for those that do, consideration of a closed-loop system is suggested.

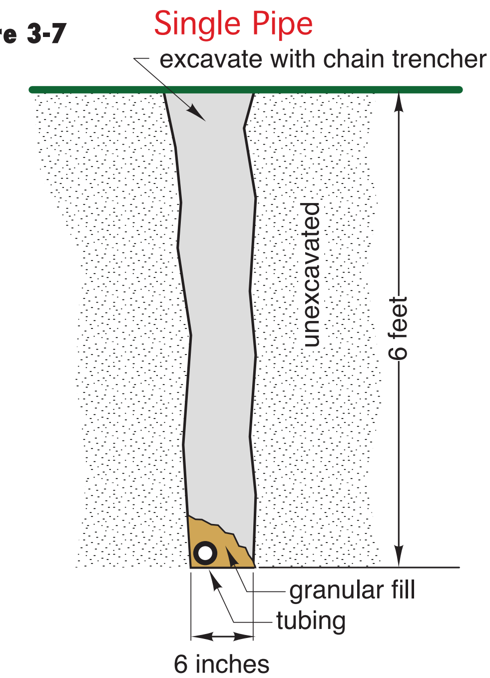
Closed loop geothermal heat pump systems extract heat from the earth (in heating mode) or dissipate heat to the earth (in cooling mode) by circulating water or a water-based antifreeze solution through a closed assembly of buried piping.

There are several ways in which tubing can be embedded in soil. Most current installation methods are classified as either horizontal or vertical earth loops.

Horizontal earth loops place tubing in trenches or other open excavations typically ranging from 4 to 8 feet deep. Placement is often determined by soil conditions, available land area and availability of various excavating equipment.

Figure 3-7 shows the cross-section of a narrow (6-inch-wide) trench created by a chain trencher. Such trenchers work best in soil that has fist size or smaller stones. A single pipe can be laid in a continuous circuit at the bottom of such a trench.

Figure 3-7



The trench shape can vary widely depending on available space. Serpentine-shaped trenches with multiple return bends are possible where placement is restrictive, as illustrated in Figure 3-8. Longer trenches with minimal return bends are generally preferred where space is available.

Figure 3-8

Courtesy of ClimateMaster

It is also possible to include two runs of piping in a single narrow trench, as shown in Figure 3-9. In such cases, the trench is partially backfilled after the first pipe is laid in place. The piping makes a U-bend at the end of the trench and returns along the backfill approximately 2 feet above the other pipe. Methods for determining the thermal performance associated with multiple pipes in a single trench have been developed.

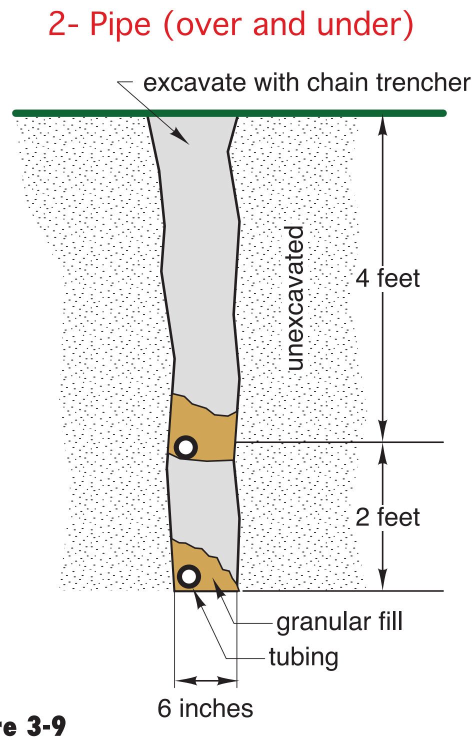


Figure 3-9

When chain trenchers are not available, or when conditions such as larger rocks are present, an excavator with a 2-foot-wide bucket is another option. The wider trenches it creates can be used to place two pipes side by side, or to duplicate the placement shown in Figure 3-9 to form what is known as a "4-pipe square" earth loop installation. Both options are shown in Figure 3-10.

It is also possible to install tubing in shapes known as "slinkies." The tubing coil is manipulated and refastened to yield the slinky shapes shown in Figure 3-11. The number of slinkies required is based on location, tubing depth and heat pump capacity. It is common to size the slinky coils to handle approximately 1 ton of evaporator load each, and manifold several such slinkies in a parallel arrangement to meet the total evaporator load. The thermal performance of slinkies can also be varied by adjusting the amount each coil overlaps the previous coil. This dimension is known as the "pitch" of the slinky.

Figure 3-10

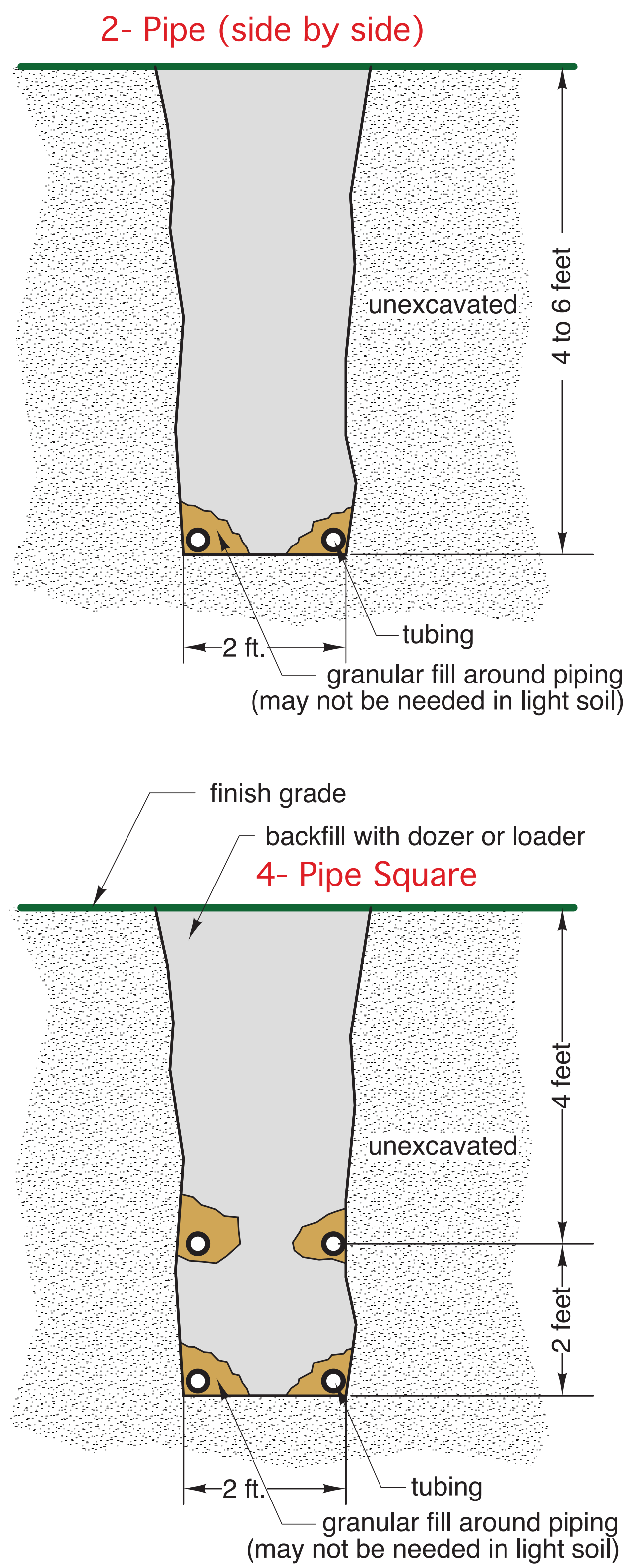


Figure 3-11a

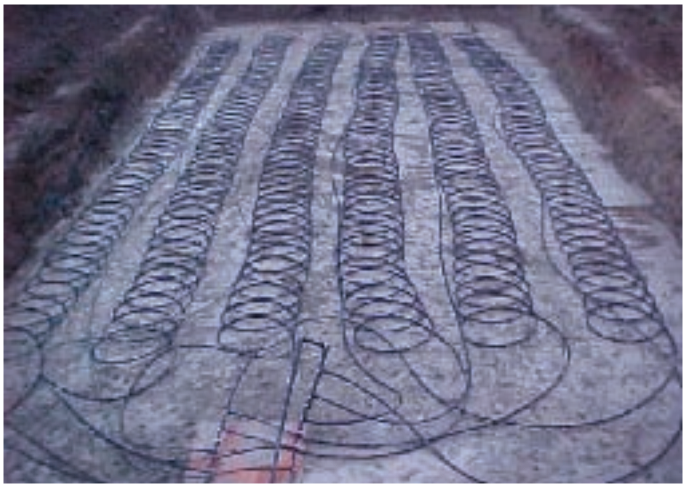


Figure 3-11b

Courtesy of GeoSystems LLC

Many installation sites, especially those in suburban or urban neighborhoods, do not have sufficient land area to make horizontal earth loops practical. The solution is to route the majority of the tubing *vertically* rather than horizontally.

Vertical earth loops require boring equipment similar or identical to that used for water wells. The choice of boring equipment is often be dictated by local availability and soil conditions. Most boreholes are 6 inches in diameter and can be as deep as 500 feet. As a guideline, 125–150 feet of borehole is required per ton of heat pump evaporator capacity.

Once bored, a U-tube assembly of HDPE or PEX tubing (also sometimes called a "probe") is inserted down the full length of each borehole. In some cases, two U-tube assemblies are inserted into the same borehole. The very tight U-bend at the bottom of the U-tube is done with a special U-bend fitting that is fusion welded to the HDPE pipe and fully pressure tested before insertion. Some installations also use a specially shaped weight attached to the lower end of the U-tube assembly to help pull it down into the borehole.

After insertion, the space between the U-tube assembly and the walls of the borehole are filled with grout. Although several grout formulations have been developed, many are based on an expansive clay called Bentonite, mixed with a fine aggregate such as sand. The objective of grouting is to fill any air voids between the tubing and soil so that conductive heat transfer is maximized. Grouting also seals the borehole so that surface contamination cannot flow down into the water aquifer. Some state and local governments have specific requirements for grouting boreholes to protect the integrity of ground water. Be sure to verify and comply with any such local requirements.

After grouting, the supply and return side of each U-tube assembly are "headered" so that all the U-tube assemblies operate in parallel (e.g., one side of each U-tube assembly is connected to a supply header, while the other side is connected to a return header). The headers are typically configured for reverse return flow with stepped piping sizes to maintain approximately the same head loss per unit length. This helps ensure equal flow distribution through each U-tube assembly. This concept is shown in Figure 3-12.

Figure 3-12

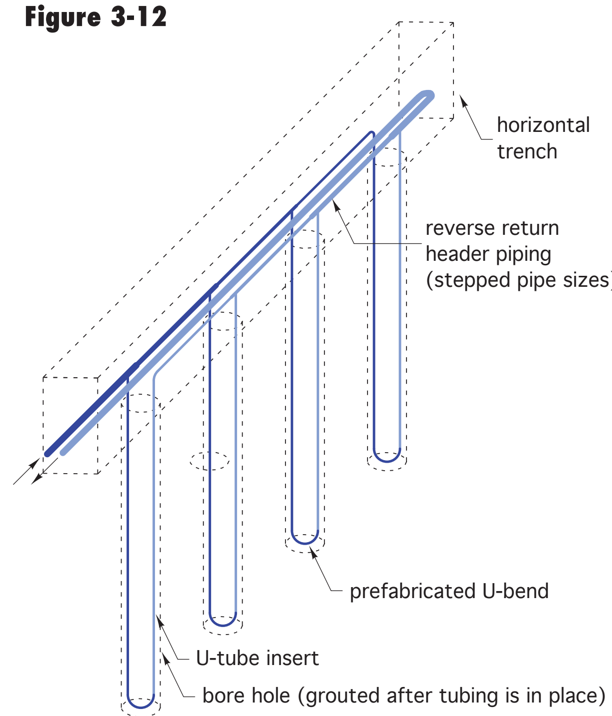


Figure 3-13

Figure 3-14

Figure 3-15

EARTH LOOP PIPING

The most commonly used earth loop piping material is high density polyethylene. More specifically, this piping is designated as PE3608 based on the ASTM F-412 standard. The pressure rating of this pipe is determined by its diameter ratio (DR), which is the ratio of the outside diameter divided by the wall thickness. Common DRs for HDPE tubing are 7, 9, 11, 13.5, 15.5, and 17.5. A diameter ratio (DR) of 11 or *lower* is suggested for buried portions of earth loops. DR-11 PE3608 piping has a pressure rating of 160 psi. The pressure ratings of DR-9 PE3608 tubing is 200 psi. Keep in mind that lower DRs imply greater wall thickness, and greater wall thickness creates greater thermal resistance across the pipe wall. The latter is undesirable from the standpoint of heat transfer.

HDPE is a thermoplastic. As such it can be repeatedly melted and reformed. This property allows HDPE pipe to be joined using heat fusion welding. When done correctly, the resulting joint is stronger than the piping itself and can maintain a leak-proof joint for many decades.

Heat fusion welding is done in three ways:

- Butt fusion welding
- Socket fusion welding
- Using electrofusion fittings

Butt fusion welding requires several specialized tools. One is a fixture tool, shown in Figure 3-13, that holds the two pipe ends in precise alignment. Moving the sloped handle of this tool moves one of the pipes in a direction parallel to its centerline. The other pipe end does not move but is held rigidly in place, parallel to the other tube.

Figure 3-16

Courtesy of McElroy Manufacturing

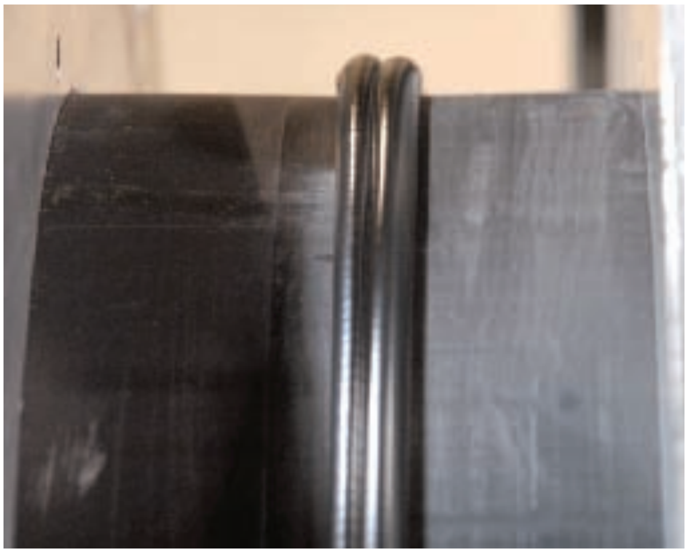
Once the two piping ends are clamped into this fixture tool, a rotary facing tool, shown in Figure 3-14, is inserted between the two pipe ends.

The ends of both pipes are simultaneously pressed against the rotating cutter head of the facing tool, which precisely trims the end of each pipe to a clean and square face.

The facing tool is then removed, and the two ends of pipe are brought together to check alignment.

After this, the heating tool, shown in Figure 3-15, is inserted between the pipe ends, and they are pressed against it. The heating tool raises the temperature of the ends of each pipe to approximately 500ºF. At this point, the pipe ends are pulled apart, the heating tool is removed and the semi-molten pipe ends are immediately pressed together. They immediately bond to each other and are held in this final position by the locked fixture tool until they cool (see Figure 3-16).

Figure 3-17



The resulting fusion joint is distinguished by a "double rollback bead" seen in Figure 3-17. Once the joint has cooled for a few minutes, it is extremely strong and ready for service.

Another technique for thermally welding HDPE pipe is called *socket* fusion. It involves joining pipe with fittings. The heating tool surfaces are shaped so that they simultaneously heat the inside of the fitting socket and the outside diameter of the tubing. Once these surfaces have reached a nominal 500ºF temperature, the pipe and fitting are pulled off the heating tool and immediately pushed together—without twisting. The semi-molten surfaces bond, and the joint is allowed to cool. Figure 3-18 shows a HDPE piping being joined to a fitting using socket fusion.

Figure 3-18

Courtesy of Universal Plumbing

Electrofusion is the process of joining HDPE pipe with specialized fittings. All electrofusion fittings are manufactured with internal heating wires surrounding the inner face of their sockets. These heating wires connect to the electrodes projecting from the sides of fitting shown in Figure 3-19.

Figure 3-19

Courtesy of Elofit

Before electrofusion, the sockets of the fitting are wiped down with a solvent to remove any dirt or grease. The exterior surface of each tube end is "shaved" with a special tool and then cleaned with a solvent. The ends of both tubes are then inserted into the fitting. This assembly is then clamped into a fixture tool that ensures proper insertion depth and alignment. A specialized electrical power supply is then connected to the electrodes on the fitting to provide low voltage/high amperage power for heating. The heating elements within the fitting quickly reach melting point temperature, and the outer surface of pipe is fused to the socket of the fitting.

Crosslinked polyethylene tubing (a.k.a. PEX-A) can also be used for buried earth loops. In North America, the use of PEX tubing for earth loops is relatively new in comparison to non-crosslinked PE3608 tubing. Being a thermoset polymer, PEX tubing *cannot* be joined by heat fusion, as is common with PE3608. Any buried joints must be made using mechanical couplings approved for such purpose by the tubing manufacturer. In many instances where PEX tubing is used for earth loops, the system is planned so that continuous lengths of tubing, free of any joints, are used for the buried portion of the earth loop. The ends of the tubing are joined to a manifold station mounted in an accessible location, either inside or outside the building.

MANIFOLD-BASED EARTH LOOPS

Most earth loop heat exchangers consist of multiple parallel piping paths that are joined to a common header system. The header is often fabricated using socket or saddle fusion to "tee" each parallel earth loop branch into the header. The size of the header tubing is typically varied (e.g., “stepped”) along the length of the header. This is done to approximate a constant head loss per 100 feet of header, which helps balance flow through individual circuits connected in a reverse return arrangement. The required fusion joints are all done in the excavated trenches. When all joints are completed, the entire earth loop assembly is pressure tested with compressed air to confirm that there are no leaks. Once its pressure integrity is verified, the earth loop is ready for backfill.

Although this “trench-based” fabrication system has been successfully used on many installations, it does, at times, have to be performed under less than ideal conditions. Working with fusion welding equipment under cold, wet and muddy conditions requires special care to ensure the joints being made are clean, dry and properly heated.

An alternative method of constructing parallel earth loops involves bringing all parallel circuits to a specially designed manifold station. In some respects, this approach is similar to routing multiple radiant panel heating circuits to a common manifold station. However, the manifold stations used for earth loops are typically larger in diameter to accommodate higher flow rates. They are also typically constructed of polymer materials since the operating temperature and pressure range of earth loops is well within what these materials can withstand.

ADVANTAGES OF MANIFOLD-BASED EARTH LOOPS

The use of manifold-based earth loops provides several advantages relative to earth loops created using buried fusion joints. They include:

• There is no need to fabricate a header within excavated trenches.

• The possibility for installing several different earth loop configurations without need of fusion joints, and thus no need of fusion equipment.

• Eliminating the need of reverse return piping to help balance flows through all parallel branches.

• Eliminating the need to step pipe sizes along site-built extended headers to maintain approximately constant head loss per unit of length. This eliminates having to work with multiple sizes of earth loop piping and the need for associated tooling.

• The outgoing and return temperatures of the earth loop are easily monitored by thermometers on the manifold.

• The possibility for extending the manifold to accommodate more earth loop circuits.

When the manifold station includes *isolation and flow indicating/balancing valves,* additional advantages include:

• Each circuit of the earth loop can be independently flushed during filling and purging. This significantly reduces the size of the flush pump required to purge the system of air.

• The flow rate through each earth loop circuit can be verified and adjusted if necessary.

• When necessary, circuits of different length and/or pipe size can be used and properly balanced at the manifold station.

• If a buried branch circuit ever fails due to future excavation, drilling, etc., it can be completely isolated from the remainder of the system at the manifold station.

Geothermal manifold stations can be located inside the building served by the heat pump system. They can also be located in an accessible vault or service chamber located outside the building.

As is true with radiant panel heating, manifold stations can be site-built from a variety of materials. However, when factors such as joint integrity, final appearance and installation time are considered, it is usually better to use a pre-manufactured manifold station built specifically for that purpose. Figure 3-20 shows the modular geothermal manifold station available from Caleffi North America.

Figure 3-20

Figure 3-21

Figure 3-22a

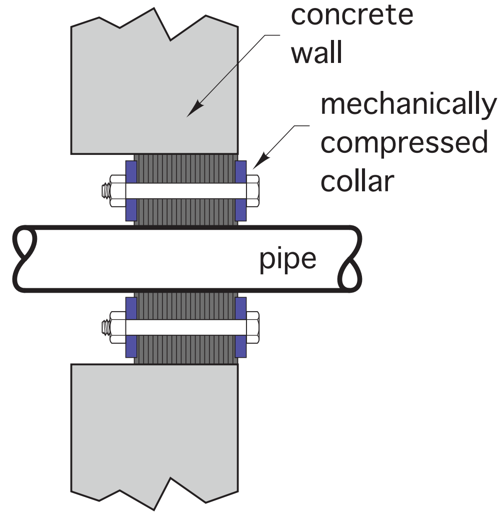


Figure 3-22b

This modular manifold is factory assembled to match the number of parallel earth loop circuits. It includes tapings for purging valves, temperature gauges and air vents. This manifold can also be equipped with several types of valves for functions such as circuit isolation, measuring flow rate in each circuit and adjusting the flow rate in each circuit. Figure 3-21 shows a four-circuit geothermal manifold station equipped with isolation ball valves on the upper manifold, and flow metering/balancing valves on the lower manifold.

Manifold stations located inside buildings usually require two penetrations of the foundation wall for each earth loop circuit. It is important to properly detail these penetrations to prevent entry of water or insects.

One method for creating a watertight seal uses a mechanically compressed collar between the hole through the foundation wall and the outside diameter of the pipe passing through it. An example of such a collar is shown in Figure 3-22.

In situations where all the earth loop circuits come to the outside of the foundation wall at the same elevation, the holes through the foundation wall can also be at that level, as shown in Figure 3-23. The holes can be core-drilled through poured concrete or concrete blocks walls. They should be spaced far enough apart to prevent structural damage to the wall and its steel reinforcement. They must be large enough to allow compression collars to fit between the outside of the tube and the penetration hole. Manufacturers of compression collars provide tables for selecting the proper seal and penetration hole size.

In situations where the earth loop tubes are vertically stacked within the trench and come to the wall at different elevations, it may be more convenient to vertically and horizontally stagger the penetration holes, as shown in Figure 3-24.

A cross-section of a typical multiple-height pipe wall penetration is shown in Figure 3-25.

The area around the piping penetrations is backfilled with clean crushed stone to allow rapid drainage of any water that may migrate into that area. The crushed stone and soil in this area are thoroughly tamped to prevent any future settlement that could strain the piping

Figure 3-23

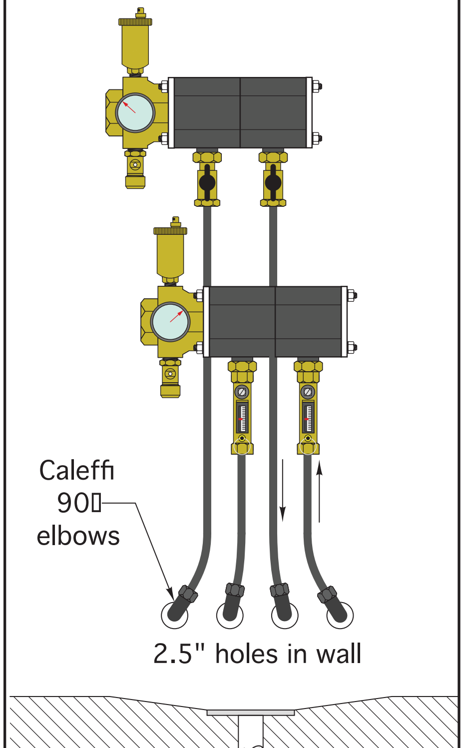


Figure 3-24

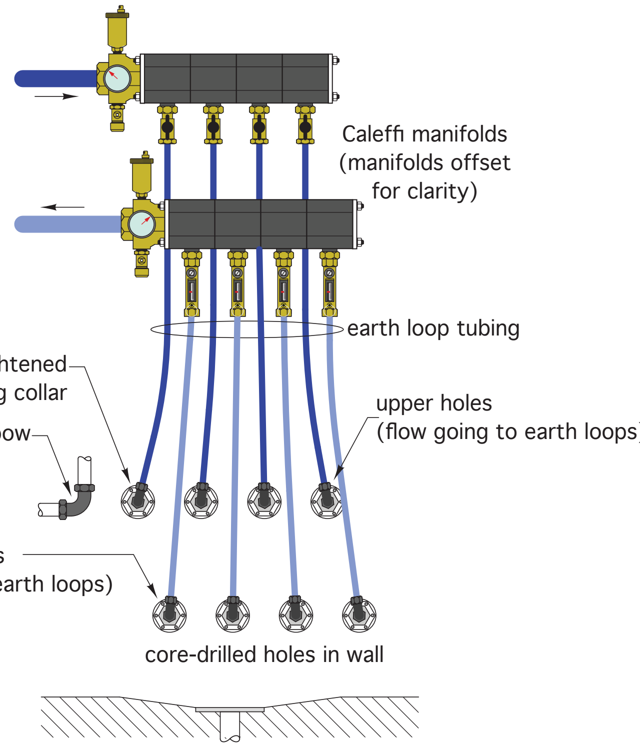
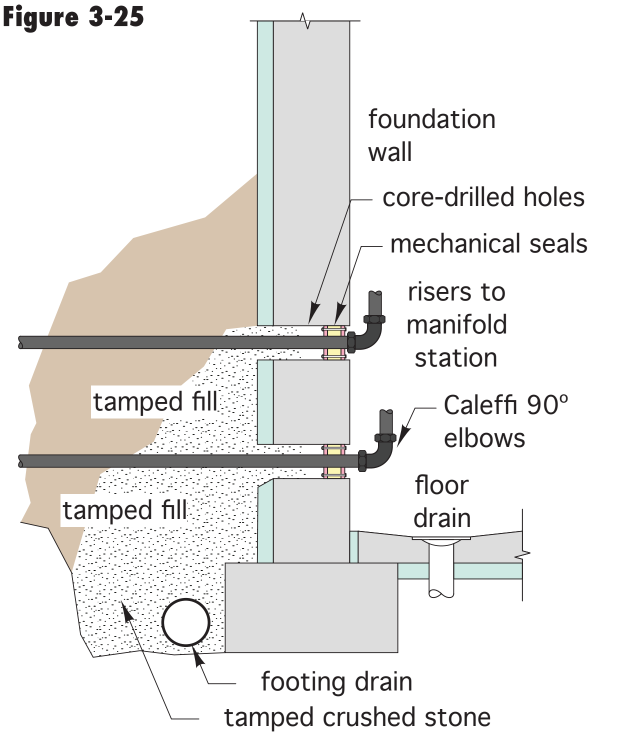


Figure 3-25



where it penetrates the wall. A floor drain located under the manifold is convenient during commissioning and possible future servicing of the system.

EXTERNAL EARTH LOOP MANIFOLDS

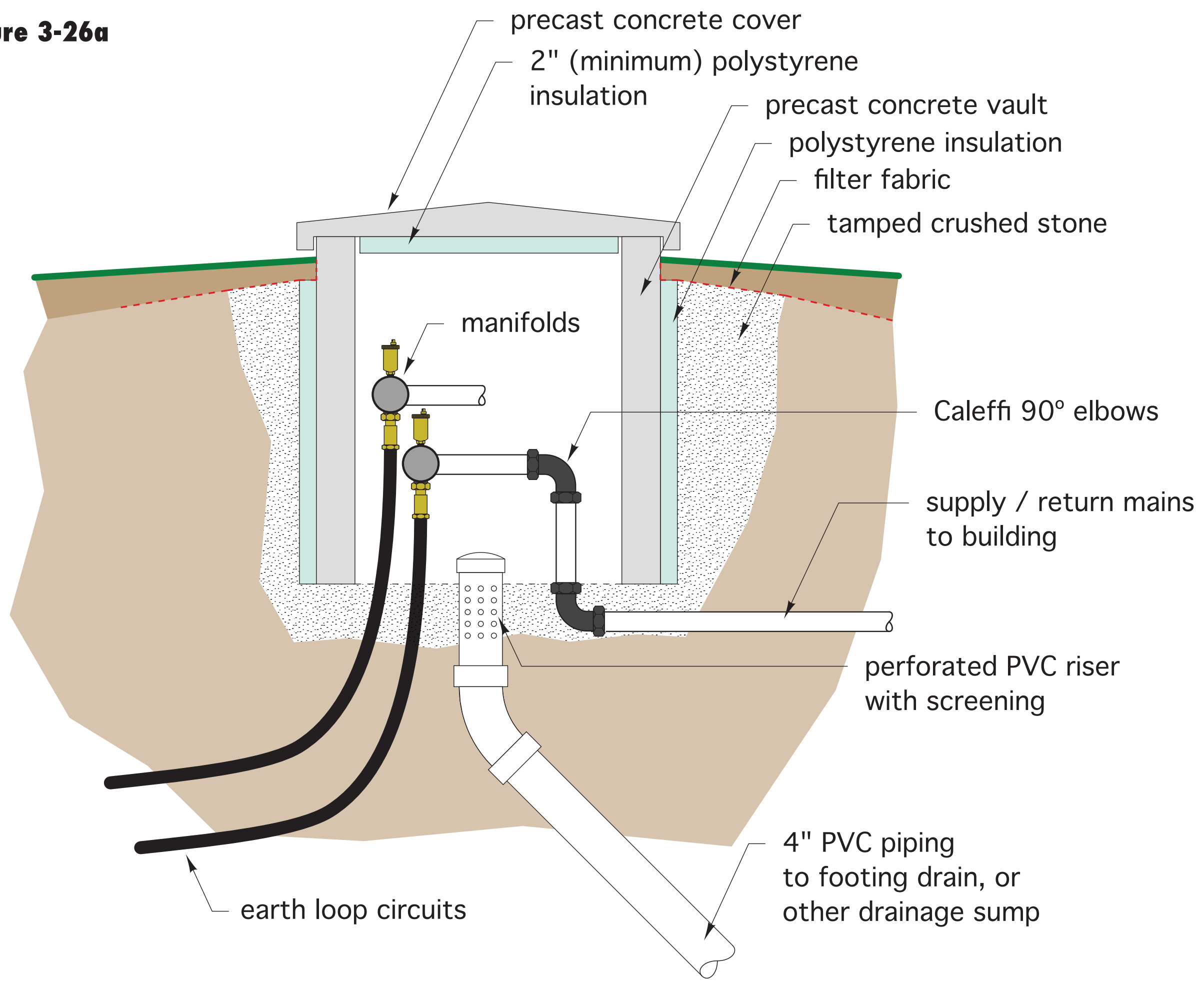
It is also possible to mount an earth loop manifold station outside the building and route a single supply and return pipe from the manifold station into the building. In all cases, the manifold should be accessible for adjustment and servicing. This requires the manifold to be mounted in some type of "pit" structure.

Figure 3-26a shows a cross-section of a concrete manifold enclosure with access cover. Such a structure could be formed using precast concrete components.

This generic construction shows an open-bottom concrete vault. Although a removable concrete cover is shown, other weather-resistant materials such as polyethylene or treated wood might also be used for the cover.

The vault is placed on a bed of tamped crushed stone and surrounded by more crushed stone to ensure that any surrounding water is quickly drained. A perforated

Figure 3-26a



PVC riser is placed so that it can collect any water that percolates down around the vault. This riser should be routed to a footing drain or other drainage outlet. This ensures that the manifold and piping will remain above the ground water level. The vault walls and cover should be insulated with extruded polystyrene board to help keep the air within the vault above freezing in cold climates. The upper soil layer should be sloped for runoff away from the vault.

Individual earth loop circuits can be routed up through the open bottom and connected to their respective manifolds. Likewise, the supply and return mains from the manifold to the building can be routed out through the open bottom of the vault. Including some 90-degree elbows in this main pipe will help absorb expansion movement and minimize stress on the manifold.

Although the manifold station could be fastened to the vault walls, or struts supported by these walls, any such fastening should allow for some expansion movement.

Figure 3-26b shows a watertight precast concrete vault as an alternative enclosure for the manifold station. Such a vault must either be "self ballasting," or be secured with non-corroding straps to a cast concrete ballast having sufficient weight to prevent the vault from rising due to buoyancy in saturated soils. Each earth loop pipe, as well as piping from the manifold to the building, enters the vault through mechanical compression seals that prevent ground water entry between the piping and the holes in the vault walls. Elbows at the manifolds allow for expansion movement of the piping. The cover is flush with finish grade, and rests on a perimeter gasket that seals to prevent surface water entry. The vault should be deep enough to maintain earth loop circuits at their nominal depths. It cold climates it is advisable to install rigid foam insulation in the upper portions of the vault to minimize heat loss.

In warmer climates it is also possible to use a prefabricated "vault" enclosure to house the manifold as shown in Figure 3-27. All piping penetrates through drilled holes

Figure 3-26b

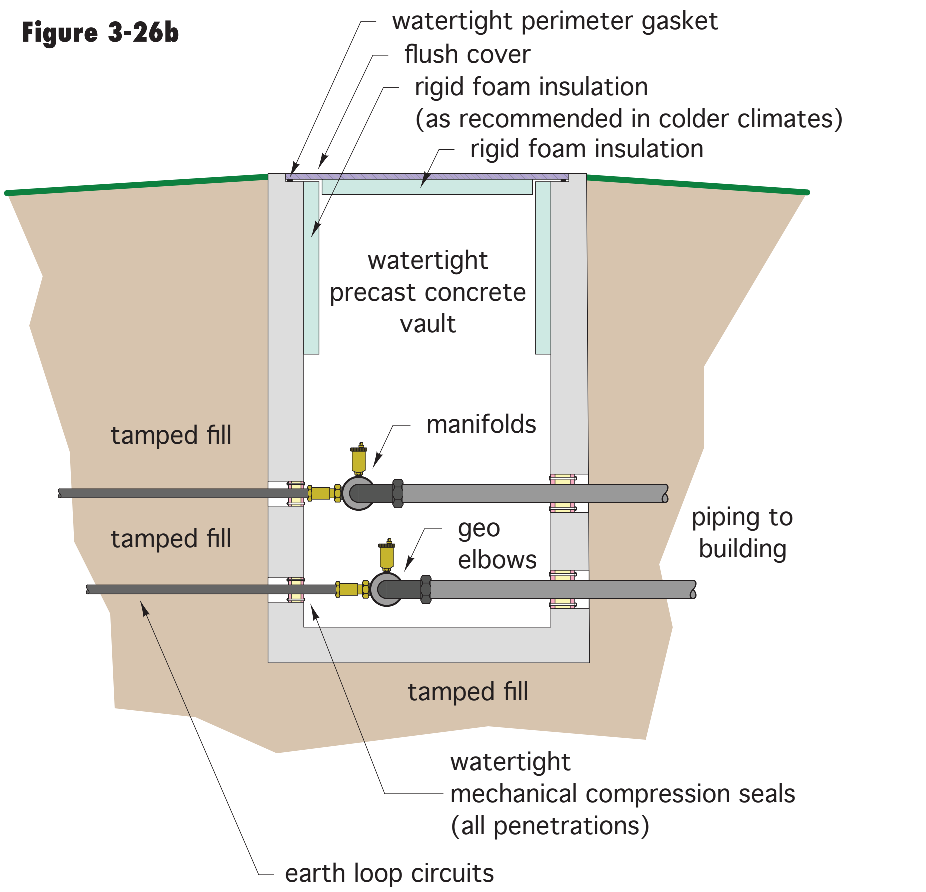


Figure 3-27

in the side of the enclosure. Such penetrations are not water-tight, and thus the bottom of the vault should be drained to prevent water accumulation. In some cases these vaults can also be stacked to maintain the earth loop tubing at greater depths.

EARTH LOOP SIZING

The amount of tubing required for a given earth loop depends on several variables, including:

- The heating and cooling capacity of the heat pump
- The heat pump's capacity compared to the building's design heating and cooling load
- The minimum allowed temperature of the earth loop fluid during the heating season
- The maximum allowed temperature of the earth loop fluid during the cooling season
- The arrangement of the tubing within trenches or boreholes
- The diameter and wall thickness of the tubing
- The average depth of the tubing
- The thermal conductivity, density and moisture content of the soil

The calculations needed to assess the listed conditions are provided in the reference given in Appendix B. The procedure requires calculation of the length of earth loop required based on the heating load as well as the cooling load. The longer of these two lengths is then selected. In cold climates, the earth loop length will usually be set by the heating requirement. Likewise, in warm climates, the earth loop length will typically be determined by the cooling load.

Some general observations about earth loop length are as follows:

- Wet and dense soils are preferable to dry and light soils. Water-saturated soils allow for good thermal diffusion, and thus tend to reduce the amount of buried tubing.

- Horizontal earth configurations with greater average piping depth tend to require less tubing.

- Multiple pipes placed close to each other are not as effective at gathering surrounding heat as are single tubes placed several feet apart. However, multiple pipes within a single trench can greatly reduce the amount of trenching required, and they often provide a more economical alternative relative to single-tube trenches.

• Many horizontal earth loops in cold climates operate with an antifreeze solution that remains free of ice crystals at temperatures of 15–20ºF. A common minimum "design" earth loop temperature is 30ºF. Increasing this temperature 3–5ºF can significantly increase the amount of tubing required in the earth loop. Decreasing this temperature will reduce the amount of tubing required, but at the expense of reduced heat pump performance.

• Horizontal earth loops will experience greater temperature variation between fall and spring compared to vertical earth loops. This allows the heat pump to achieve relatively high heating capacity and COPs in fall. However, both of these performance indices will decrease as winter progresses, and tend to be at or close to minimum in late winter or early spring.

• Because of relatively minor variations in deep soil temperature, heat pumps supplied from vertical earth loops will have relatively consistent heating capacity and COP over the entire winter.

• Most earth loops should be designed to ensure that flow through them remains turbulent at their minimum fluid temperature. Turbulent flow provides better heat transfer between the tube wall and flow fluid.

• Earth loops should be carefully backfilled to avoid air gaps around tubing, as well as damage to tubing due to large or sharp rocks. If such rocks are present, the tubing should be "bedded" in a layer of fine soil or sand to protect it against damage during backfill.

• All earth loops, especially those with buried (inaccessible) fusion joints, should be pressure tested with compressed air to at least 75 psi for at least 24 hours to ensure there are absolutely no leaks.

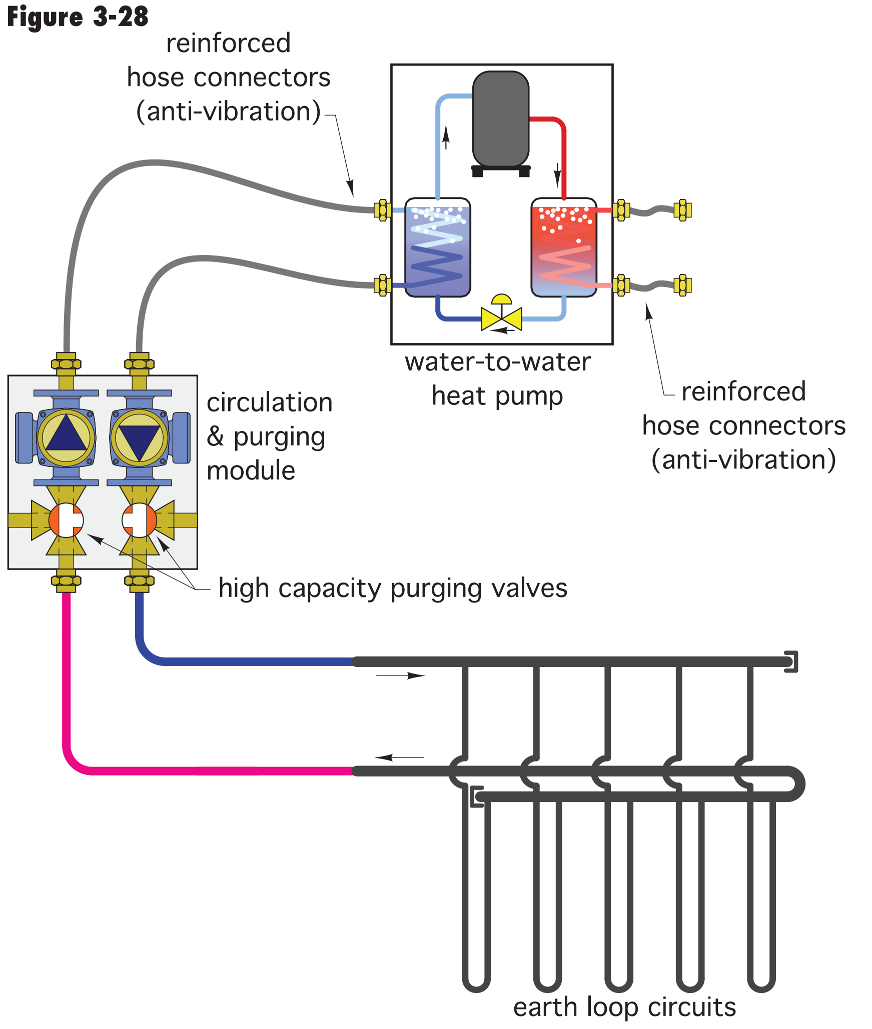
INTERIOR EARTH LOOP PIPING

There are varied options regarding the best way to connect an earth loop to one or more heat pumps. There are also a variety of products for doing so. In North America, it is common for piping between an earth loop and single heat pump to be installed as shown in Figure 3-28.

The circulation and purging module contains one or two circulators and two high flow capacity purging valves. The latter are used to add fluid to the earth loop and purge it of air. When two circulators are used in the module, they are arranged so they operate in a series "push/pull" configuration. This doubles the head provided by a single circulator. The higher head may be required to provide proper flow in longer earth loops.

The traditional piping shown in Figure 3-28 does not contain several components that some designers deem preferable, or even *essential,* for achieving optimal earth

Figure 3-28



loop performance—specifically, an expansion tank, air separator and dirt separator.

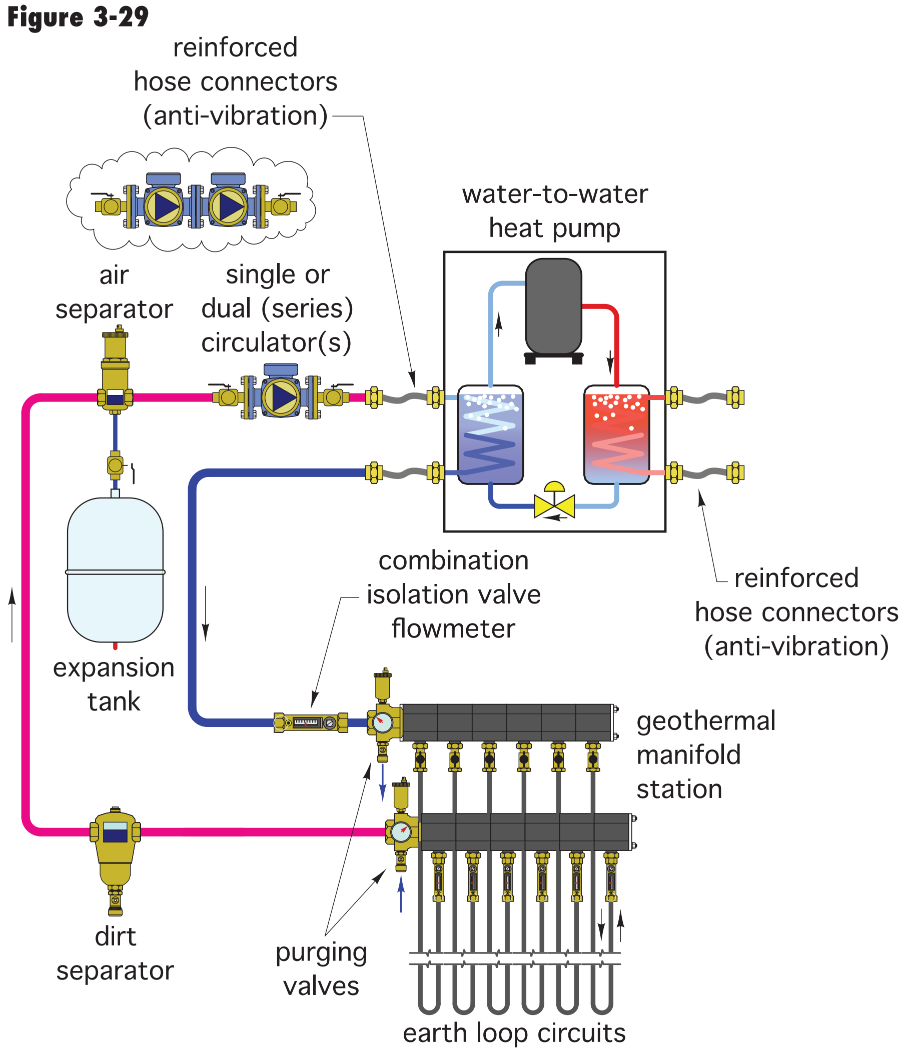
Earth loops are closed-loop hydronic systems. As such, the less air they contain, the better. Less air means better heat transfer, higher pump efficiency, less potential for scaling and corrosion of metal surfaces, reduced possibility of circulator cavitation and quieter operation. Although most of the *bulk* air initially in the earth loop can be removed by forced-water purging, dissolved air cannot. A microbubble-capable air separator placed where the fluid is at its highest temperature will reduce dissolved air content over time.

High efficiency dirt separation is also desirable. Again, forced-water purging can remove larger dirt particles, but not necessarily smaller particles, especially when no filtering is used during purging. Over time, a low-velocity zone dirt separator can remove particles as small as 5 microns. This reduces wear on circulators, as well as fouling of heat transfer surfaces. The result will be improved thermal performance relative to systems that do not have dirt separation capability.

An expansion tank will significantly reduce pressure fluctuations within any earth loop. Wide pressure fluctuations are not desirable. Without an expansion tank, significant pressure drops can occur when the earth loop is being warmed to reject heat. This can cause circulator cavitation. Large pressure increases when the loop is being cooled may cause weepage of fluid at threaded or clamped fittings. Section 9 details the underlying reasons for these wide pressure fluctuations, and describes how to properly size an expansion tank to avoid them.

Figure 3-29 shows a different configuration for interior earth loop piping.

Figure 3-29



Because the earth loop is manifolded with individual isolation valves for each circuit, each circuit can be purged individually. This eliminates the need for high-capacity purging valves.

The loop is also equipped with a high-performance dirt separator positioned to capture dirt particles coming from the exterior portion of the earth loop before they pass through the circulator or heat pump.

A microbubble-capable air separator is also present to reduce the dissolved air content of the earth loop fluid over time.

An expansion tank is used to reduce pressure fluctuations within the earth loop.

Either a single circulator or “close-coupled” pair of circulators is used, depending on the flow and head requirements of the circuit. In either case, the circulator inlet is located close to the expansion tank. Because the expansion tank connection is the point of no pressure change within the circuit, the differential pressure created by the operating circulator(s) increases the pressure within the heat pump and earth loop. Increased fluid pressures reduce the potential for precipitation of dissolved solids within the heat pump, especially in systems that operate at higher loop temperatures during cooling mode operation.

The combination isolation valve/flow meter shown near the inlet to the geothermal manifold station allows the earth loop to be purged separately from the interior portions of the circuit. It also provides verification of earth loop flow rate during commissioning and future maintenance. Appendix E further describes how this valve, in combination with two temperature sensors, can be used to estimate the thermal performance of the heat pump.

EARTH LOOP FLUIDS

Because the evaporators in most geothermal heat pumps can operate at refrigerant temperatures well below freezing, it is common to use an antifreeze solution rather than 100% water in earth loops. Several types of antifreeze solutions based on salts, glycols and alcohol additives have been used in geothermal systems. Each of these solutions has strengths and limitations.

Salt-based solutions of calcium chloride and potassium acetate have been used in some earlier generation geothermal heat pump systems. While offering acceptable environmental characteristics, salt-based solutions often prove corrosive to metal components, including cast iron and copper. These solutions have also shown a propensity to leak through certain pipe joints due to their low surface tensions. At present, salt-based solutions are not widely used in geothermal heat pump applications.

Alcohol-based fluids include diluted solutions of methanol and ethanol. Methanol, although good from the standpoint of having relatively high specific heat, good freezing point depression and low viscosity, has the negative of high oral toxicity. It is also considered a flammable substance, even in 20% methanol/80% water concentrations. For these reasons, some municipalities and states have specifically banned its use in geothermal earth loops. Ethanol solutions as low as 20% concentration are also considered flammable liquids according to NFPA standard 325. Any ethanol used for antifreeze purposes is "denatured" (e.g., rendered undrinkable through additives, some of which may be toxic). Premixed solutions of ethanol and deionized water are commercially available for geothermal applications in North America. Installers should follow all information provided by suppliers regarding handling, storage and disposal of such fluids.

Although both types of alcohol-based solutions have been successfully used in geothermal heat pump systems, it is imperative to verify any local ordinances or OSHA regulations that may constrain or restrict their use. Safety regulations may require a separation of at least 10 feet between the alcohol-based fluid and any potential ignition source. They may also require that any open container containing an alcohol-based fluid, such as a flushing cart, remains outside the building. Other precautions include electrical bonding and grounding of containers during fluid transfer to prevent the possibility of arcs due to static electricity.

It is also imperative that any air-venting equipment in piping containing alcohol-based solutions be equipped with vent discharge piping that can carry any vapors outside the building and discharge them to open air away from any electrical equipment or other potential sources of ignition. Equipment such as Caleffi DISCAL air separators, Hydro Separators or other air-venting devices that are used in systems with alcohol-based solutions must be equipped with such vent discharge piping leading to safe discharge to outside air. Special fittings are available from Caleffi for this purpose (as shown in figure 3-30).

Figure 3-30

The most widely used antifreeze in geothermal heat pump applications is a water-based solution of food-grade propylene glycol. Concentrations of 20% are common. Food-grade propylene glycol is not toxic. Commercially available propylene glycol sold for use in HVAC systems contains small amounts of other chemicals called "inhibitors." These chemicals make the solution less acidic, discourage biological growth and minimize corrosion potential. Because it is non-flammable and non-toxic, it is acceptable to allow air-venting devices in systems containing propylene glycol to discharge directly into mechanical rooms.

4. HEAT EMITTERS FOR HYDRONIC HEAT PUMPS

Not every hydronic space heating distribution system is suitable for use with a hydronic heat pump. *Distribution systems that operate at low water temperatures are greatly preferred because they allow for higher heating capacity as well as high coefficients of performance (COP).*

Space heating distribution systems that provide design heating output using supply water temperatures no higher than 120ºF will allow the majority of currently available hydronic heat pumps to deliver relatively good performance.

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 hydronic heat pumps to provide good performance include:

- Heated floor slabs with low-resistance coverings
- Heated thin-slabs over framed floors with low-resistance coverings
- Generously sized panel radiator systems with parallel piping
- High-output fin-tube baseboard

This section discusses each of these options in more detail.

HEATED FLOOR SLABS

Heated floor slabs with relatively close tube spacing and low finish floor resistances are generally well-suited for use with hydronic heat pumps. The graph in Figure 4-1 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 (ºF•hr•ft^2/Btu). The steeper the line, the better-suited the distribution system is for use with a heat pump.

For example, achieving an upward heat output of 20 Btu/hr/ft2 from a slab with no covering (e.g., Rff = 0) and 6-inch tube spacing requires the "driving ∆T" (e.g., the difference between the average water temperature in tubing and room air temperature) to be 17.5ºF. Thus, in a room maintained at 70ºF, the average water temperature in the circuit needs to be 87.5ºF. The supply water temperature to the circuit would likely be in the range of 95–98ºF. This is a relatively low supply water temperature that would allow most hydronic heat pumps to operate at reasonably good heating capacity and COP.

For comparison, consider supplying the same 20 Btu/hr/ft^2 load using a heated floor slab with 12-inch tube

Figure 4-1

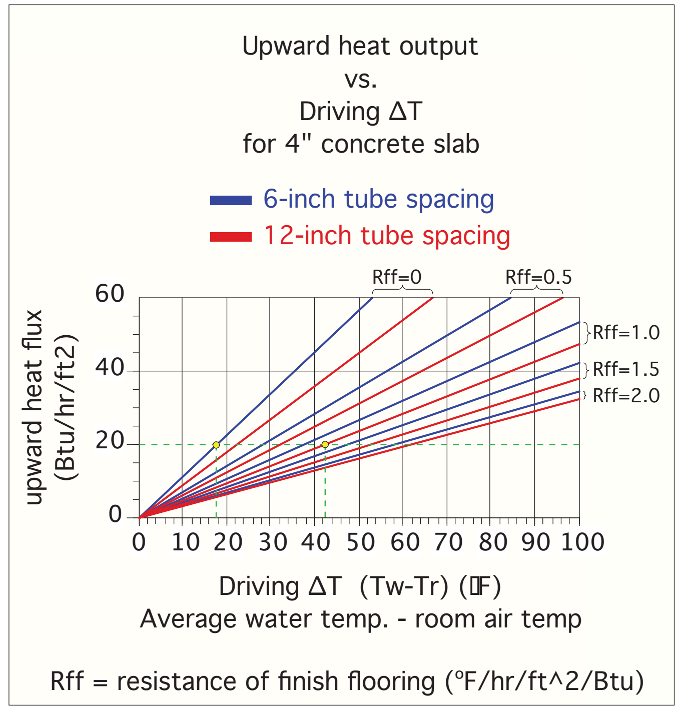


Figure 4-2

spacing and a finish floor resistance of 1.0ºF•hr•ft^2/Btu. The driving ∆T must now be 42.5ºF. The average circuit water temperature required to maintain a room temperature of 70ºF would be 70 + 42.5 = 112.5ºF and the supply temperature likely in the range of 120–123ºF. This higher temperature would reduce the heating capacity and COP of the heat pump. It may even exceed the heat pump manufacturer's recommended operating temperature limit.

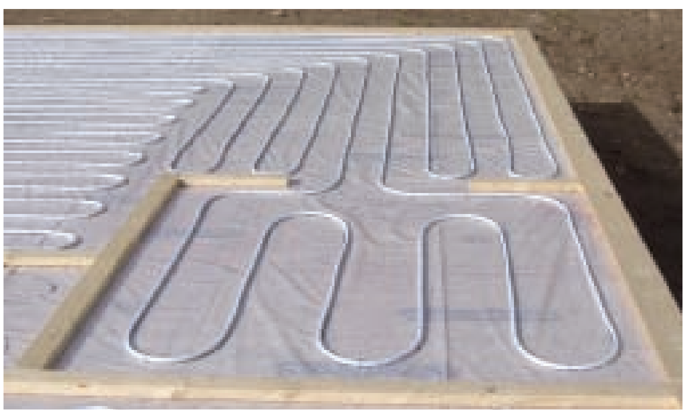
The following guidelines are suggested in applications where a heated floor slab will be used to deliver heat derived from a hydronic heat pump:

• Tube spacing within the slab should not exceed 12 inches
• Slab should have a minimum of R-10 underside insulation
• Tubing should be placed at approximately 1/2 the slab depth below the surface, as shown in Figure 4-2. Doing so decreases the required water temperature required for a given rate of heat output. Lower water temperatures improve heat pump performance.
• Bare, painted or stained slab surfaces are ideal because the finish floor resistance is essentially zero
• Any finish floors used should have a Total R-value of 1.0 or less

HEATED THIN-SLABS

Another common method of installing floor heating uses a "thin slab" (e.g., 1.5-inch to 2-inch slab thickness) poured over a wooden floor deck. Figure 4-3 shows an example of such an installation, awaiting placement of the slab material.

Figure 4-3



Courtesy of Harvey Youker

Because the slab is thinner than with slab-on-grade floors, it has slightly less heat dispersal characteristics. This translates into a slightly higher water temperature requirement for a given rate of heat output compared to that required for a slab-on-grade. This difference is slight. A 1.5-inch-thick concrete thin slab with 12-inch tube spacing and covered with a finish flooring resistance of 0.5ºF•hr•ft^2/Btu yields about 8% less heat output than a 4-inch-thick slab with the same tube spacing and finishing flooring. This can be easily compensated for by using 9-inch rather than 12-inch tube spacing.

The following guidelines are suggested:

• Tube spacing within the thin slab should not exceed 9 inches
• Floors should have a minimum of R-19 underside insulation
• Floor finishes should have a total R-value of 1.0 or less
• Never use "lightweight" concrete (not the same as poured gypsum underlayments) for heated thin slabs

OTHER SITE-BUILT RADIANT PANELS

Radiant panels can be integrated into walls and ceilings as well as floors. Several of these configurations may be suitable for use with hydronic heat pumps. The key is ensuring that the radiant panel can deliver design load output while operating at a relatively low water temperature. This helps ensure the heat pump will also operate at a relatively low fluid temperature and reasonably good efficiency.

This criterion favors radiant panels that provide high surface areas relative to their rate of heat delivery. It also favors panels that have low internal thermal resistance between the tubing and the surface area releasing heat to the room.

One example is a radiant wall panel constructed as shown in Figure 4-4.

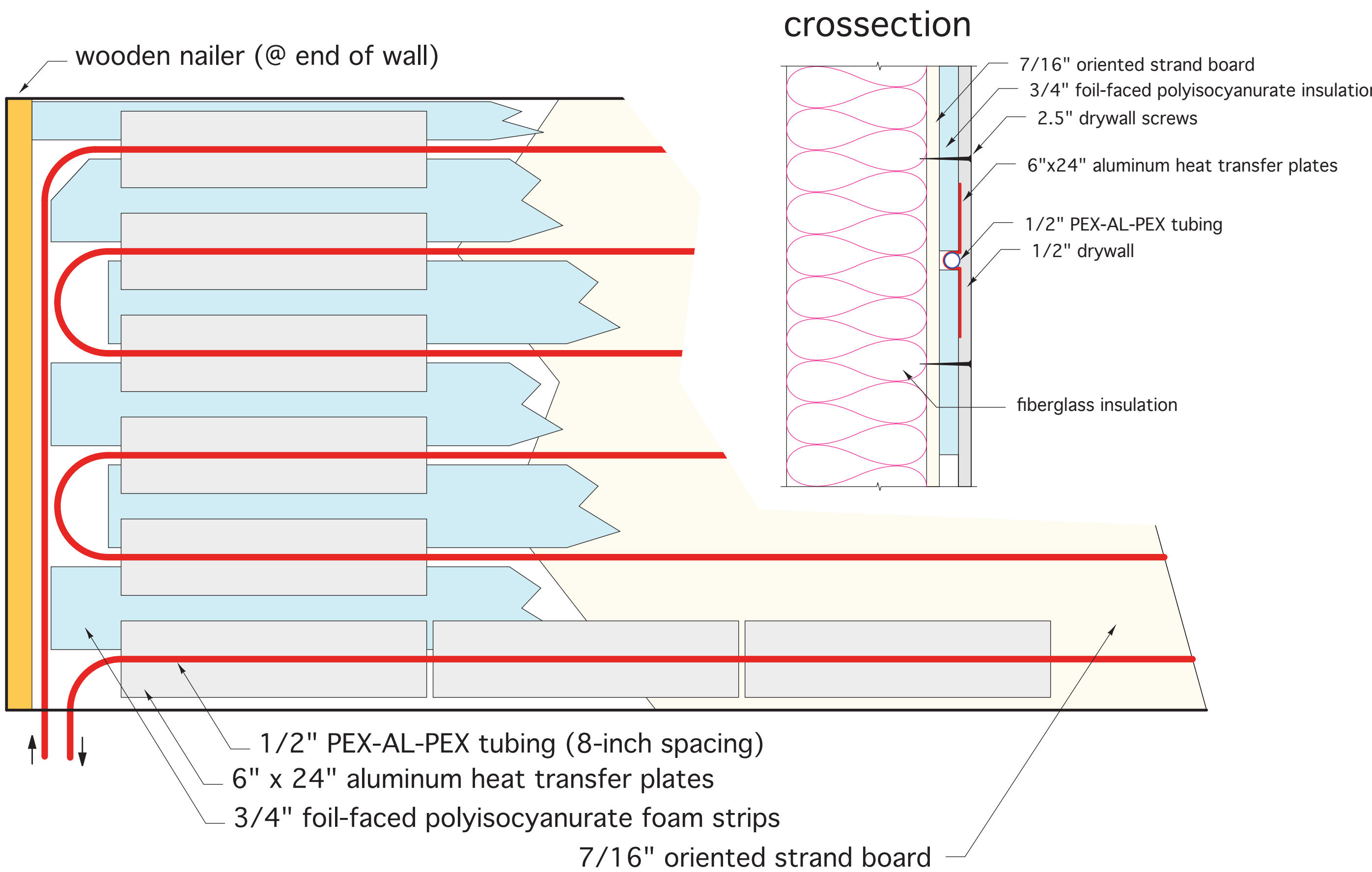
When finished, this "radiant wall" is indistinguishable from a standard interior wall. Its low thermal mass allows it to respond quickly to changing internal load conditions or zone setback schedules. The rate of heat emission to the room is approximately 0.8 Btu/hr/ft^2 for each degree Fahrenheit the average water temperature in the tubing exceeds room air temperature. Thus, if the radiant wall panel operates with an average water temperature of 110ºF in a room with 70ºF air temperature, each square foot of wall would release about 0.8 x (110 - 70) = 32 Btu/hr/ft^2. This performance makes it well-suited for use with hydronic heat pumps.

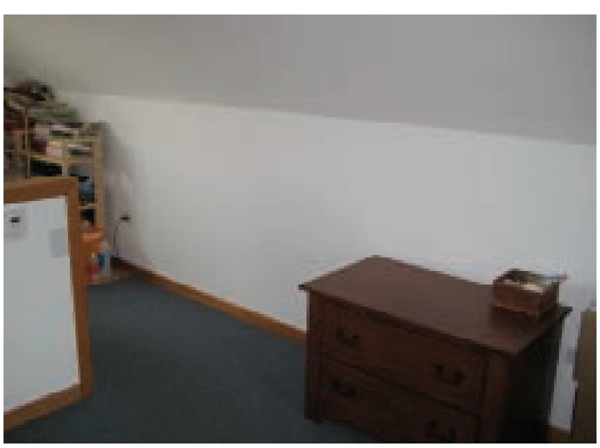
Another possibility is a radiant ceiling using the same type of construction as the radiant wall, as shown in Figure 4-5.

As with the radiant wall panel, this radiant ceiling has low thermal mass and responds quickly to interior temperature changes. Heated ceilings also have the advantage of not being covered or blocked by coverings or furniture, and thus are likely to retain good performance over the life of the building.

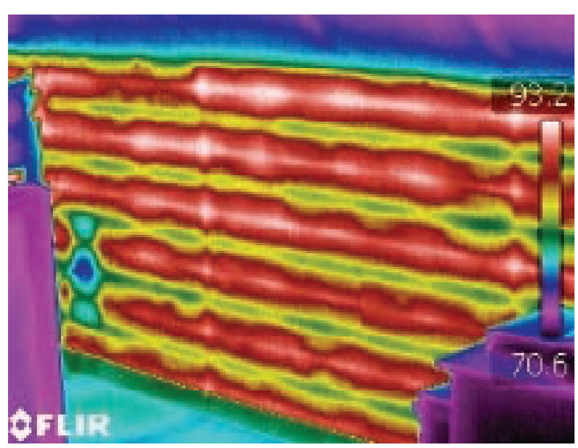
For the construction shown in Figure 4-5, the rate of heat emission is approximately 0.71 Btu/hr/ft^2 for each degree Fahrenheit the average water temperature in the tubing exceeds room air temperature. Thus, if the ceiling operated with an average water temperature of 110ºF in a room with 70ºF air temperature, each square foot of wall would release about 0.71 x (110 - 70) = 28.4 Btu/hr/ft^2. This performance makes the radiant ceiling well-suited for use with hydronic heat pumps.

Figure 4-4





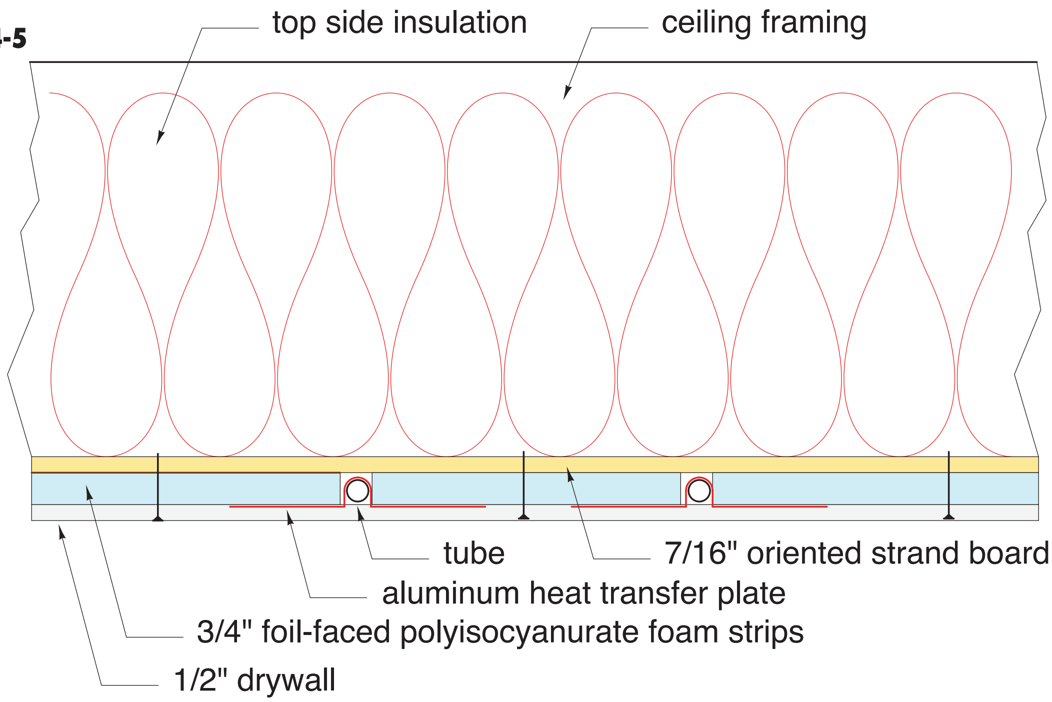
finished radiant wall



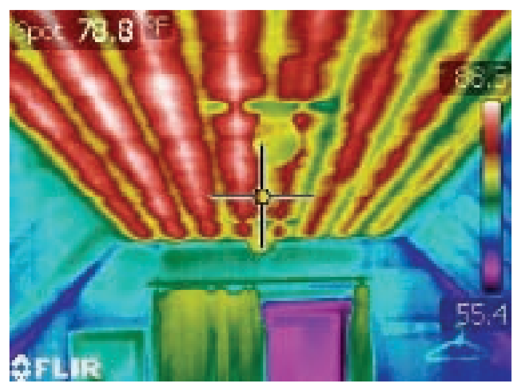
thermal image of wall in operation

$$\frac{Btu}{hr \bullet ft^2} = (0.8) \times (T_{water} - T_{room})$$

Figure 4-5



finished radiant wall



thermal image of ceiling in operation

$$\frac{Btu}{hr \bullet ft^2} = (0.71) \times (T_{water} - T_{room})$$

PANEL RADIATORS

Generously sized panel radiators can also provide good performance when used as part of a hydronic heat pump system. *Again, the suggested guideline is to size panels so they can deliver design space heating output using a supply water temperature no higher than 120ºF.* An example of a panel radiator with integral thermostatic radiator valve is shown in Figure 4-6.

Manufacturers provide output ratings for their panel radiators in either graphical or tabular form. In many cases, “reference” heat output ratings for a given panel size are stated along with corresponding water temperature and room air temperatures. Correction factors are then given, which, when multiplied by the reference heat output, give the actual heat output for specific water and room air temperatures. As an approximation, a panel radiator similar to the one shown in Figure 4-6, operating with an average water temperature of 110ºF, provides approximately 27% of the heat output it yields at an average water temperature of 180ºF. Larger panels (longer, taller and deeper) are available to increase surface area to compensate for lower operating temperatures.

Ultra-low mass panel radiators are also available. An example of one such panel is shown in Figure 4-7.

Figure 4-6

Courtesy of Harvey Youker

Figure 4-7

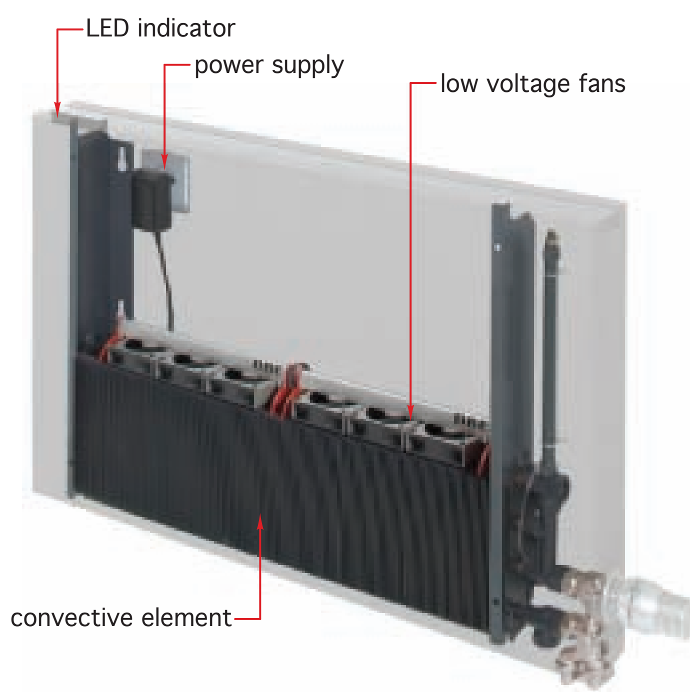
Courtesy of JAGA North America

This panel uses a convective element consisting of tubing with large surface area fins. The thermal mass of the metal and water contained in this element is very low. This allows for rapid response upon a call for heating. It also allows the unit to stop releasing heat very quickly upon a reduction or total stoppage of water flow. These characteristics are very desireable in buildings with low heat loss and the potential for significant internal heat gains from sunlight, people or equipment.

The panel shown in Figure 4-7 can also be equipped with low-power “microfans” to significantly boost thermal output at low supply water temperatures. Figure 4-8 shows a panel equipped with two groups of three fans each. A group of three fans running at full speed requires an electrical power input of only 5 watts, yet can boost thermal outputs up to 250% when operating at supply water temperatures as low as 95°F. This low temperature capability make such units well-suited for use with hydronic heat pumps.

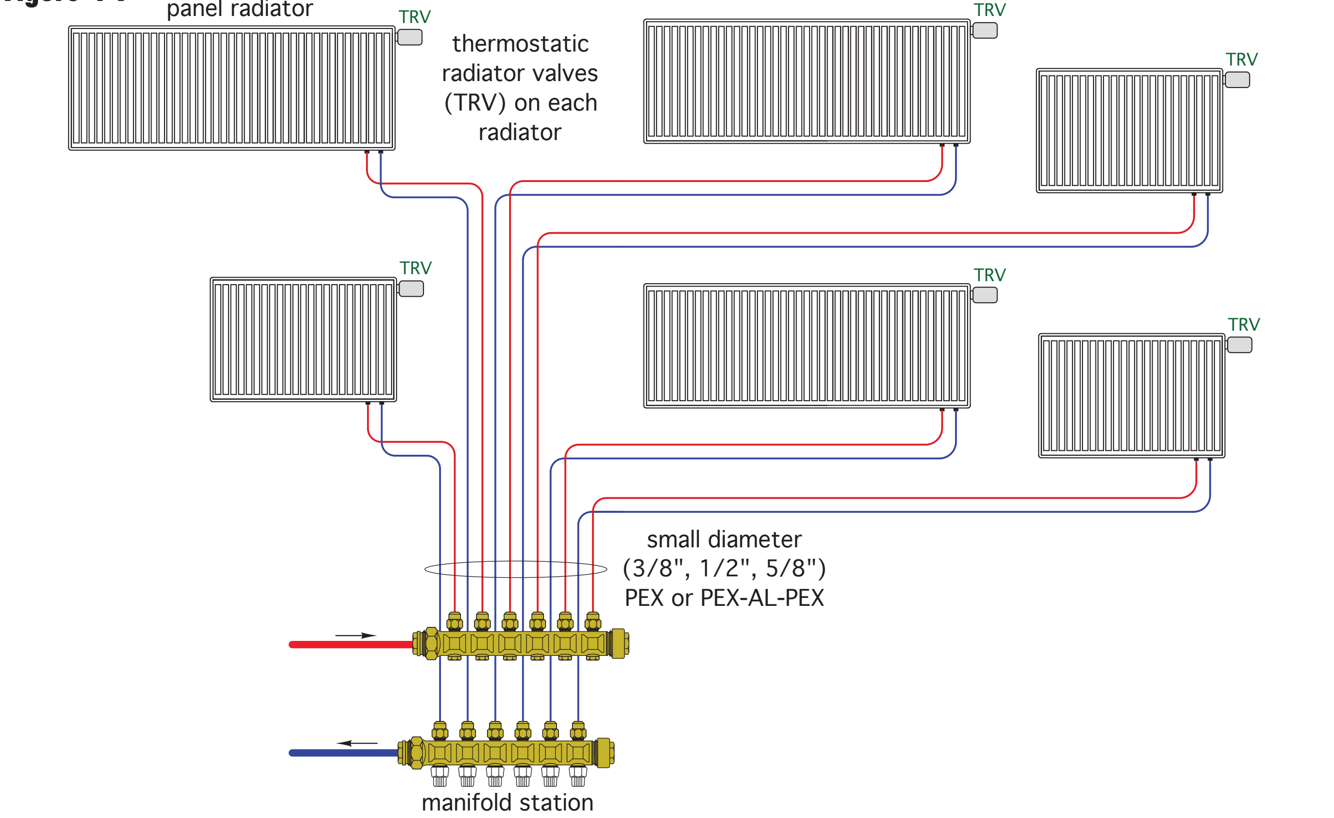
When panel radiators are used in a hydronic heat pump system, they should always be piped in parallel. Ideally, each panel radiator is served by its own supply and return piping. A manifold-based distribution system, as shown in Figure 4-9, uses small diameter PEX or PEX-AL-PEX tubing to supply each radiator. Tube sizes in such systems vary from 3/8-inch to 5/8-inch, depending on flow rate and head loss allowances. This type of distribution system is shown in several schematics in later sections.

Figure 4-8



Courtesy of JAGA North America

Figure 4-9



LOW-TEMPERATURE FIN-TUBE BASEBOARD

The hydronics industry, worldwide, is keenly aware that low-temperature heat sources such as hydronic heat pumps will be increasingly common in future systems. This has lead to reconfigurations of traditional products in ways that allow them to operate at lower water temperatures. Few products have been more traditional to North American hydronics than fin-tube baseboard.

Fin-tube baseboard was originally developed for the high water temperatures available from conventional boilers. Such baseboard is often sized based on supply water temperatures ranging from 170° to 200ºF. This is much higher than the water temperatures hydronic heat pumps can produce. Thus, traditional fin-tube baseboard is not recommended in such applications.

Figure 4-10

Source: Smith Environmental

Figure 4-11

Source: Smith Environmental

However, new products recently introduced in the North American market are aimed at eliminating this limitation. The fin-tube element shown in Figure 4-10 has significantly greater fin area compared to that of a standard element. It also has two tubes passing through the fins. This allows significantly higher heat out at lower water temperatures. The rated output of this element when both pipes operate in parallel is 272 Btu/hr/ft at an entering water temperature of 90ºF, and 532 Btu/hr/ft at a water temperature of 120ºF, both at a total flow rate of 1 gallon per minute. The installed appearance (see Figure 4-11) is similar to that of conventional baseboard.

CAST IRON RADIATORS

Cast iron radiators sized for steam heating but converted for use with higher temperature water are also unlikely to be suitable for use with hydronic heat pumps. The possible exception would be a building that has undergone extensive weatherization since the steam radiators were installed. In some cases, the significant reduction in heating load may allow design heat output to be attained at water temperatures no higher than 120ºF. This would allow them to function with hydronic heat pumps. In such cases, the original radiator system should also be internally cleaned and flushed to remove any accumulated residue associated with steam heating. A high quality dirt separator should also be installed in the distribution system to ensure continuous cleansing of the system fluid.

5. HEATING-ONLY APPLICATIONS

Hydronic heat pumps, when combined with modern distribution and control systems, can serve in a wide variety of applications. This section presents templates for several "heating only" systems. Such systems would be applicable in buildings that do not require cooling, or buildings with alternative or existing cooling systems.

SINGLE-ZONE, HEATING-ONLY SYSTEM

The system shown in Figure 5-1 is a simple, single-zone, heating-only application. The heating capacity of the heat pump is assumed to be matched to the heat dissipating ability of the low-temperature radiant panel distribution system. *The thermal balance between heating capacity and the heat dissipation should occur at the lowest practical supply water temperature.* The lower this supply water temperature can be, the higher the heating capacity and COP of the heat pump. A suggested maximum supply temperature under design load conditions is 120ºF.

Because this is a single-zone system, there is no need of a buffer tank. The simplest way to control this system is to turn on the heat pump, along with the two circulators, whenever there is a call for space heating. With the heat output of the heat pump matched to the heat dissipation ability of the distribution system, the supply water temperature will be "self stabilized" by thermal equilibrium.

Figure 5-1

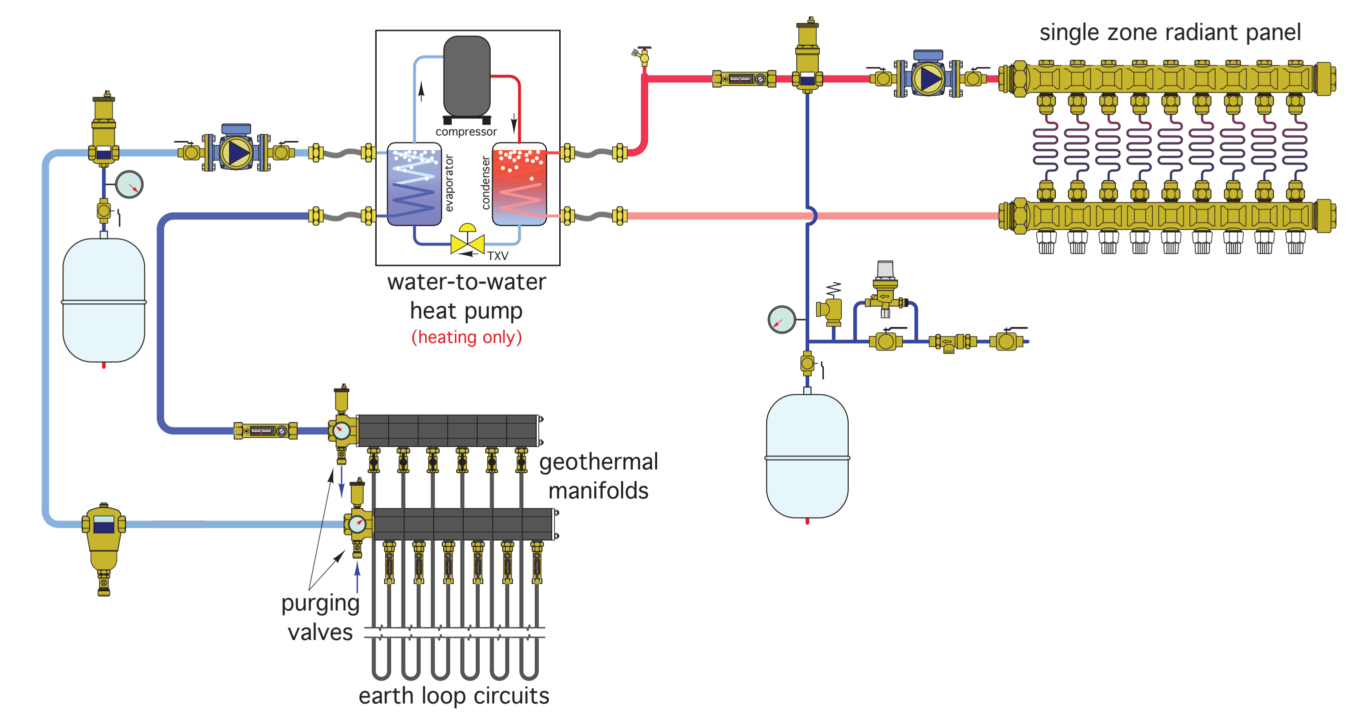
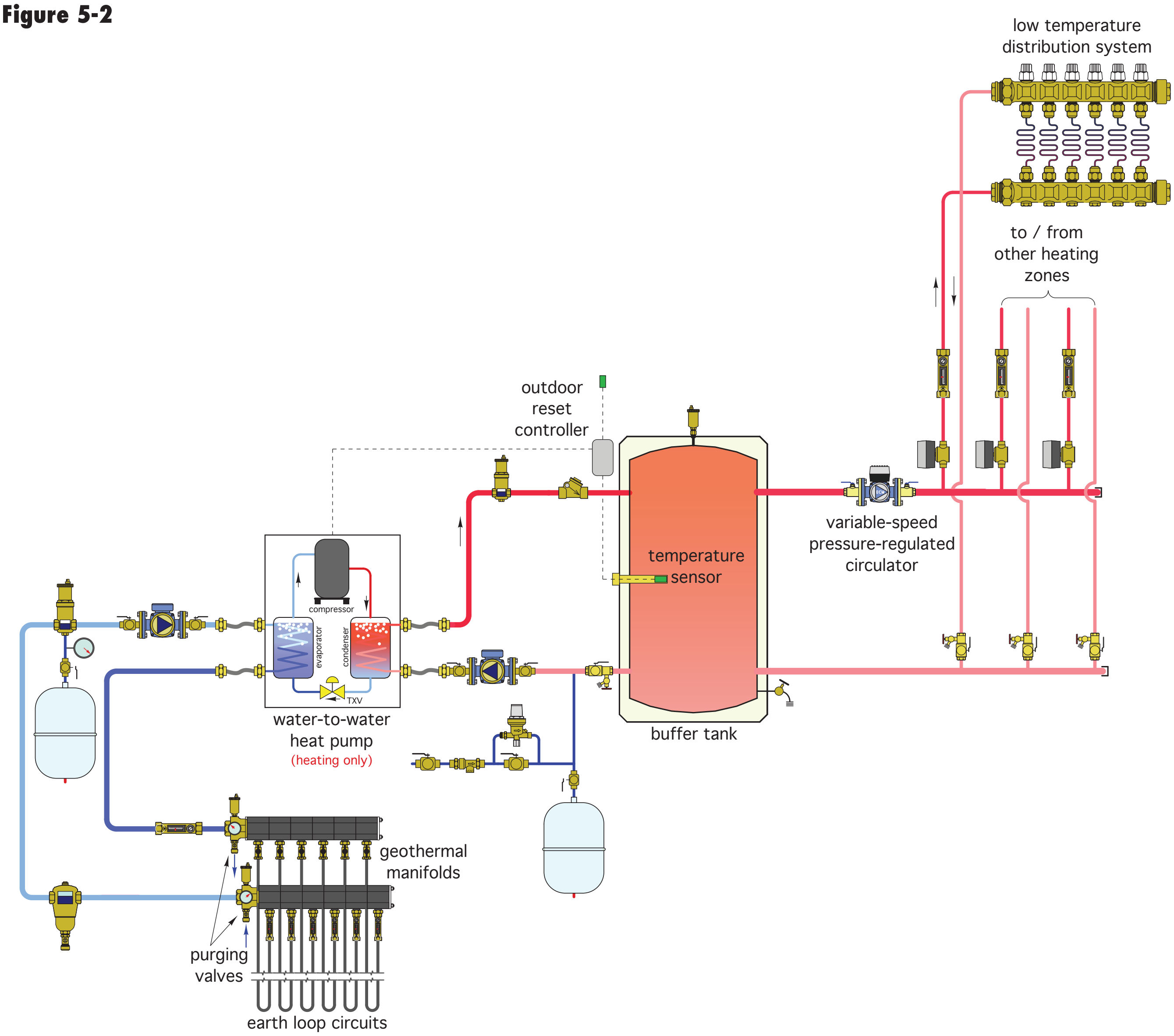


Figure 5-2



Another option would be to provide constant circulation in the distribution system during the heating season, and operate the heat pump and earth loop circulator based on outdoor reset control. This would allow the heat pump to operate at reduced supply water temperatures under partial load conditions and should improve seasonal average COP. Be sure to set the differential of the reset controller to avoid short cycles under partial load conditions.

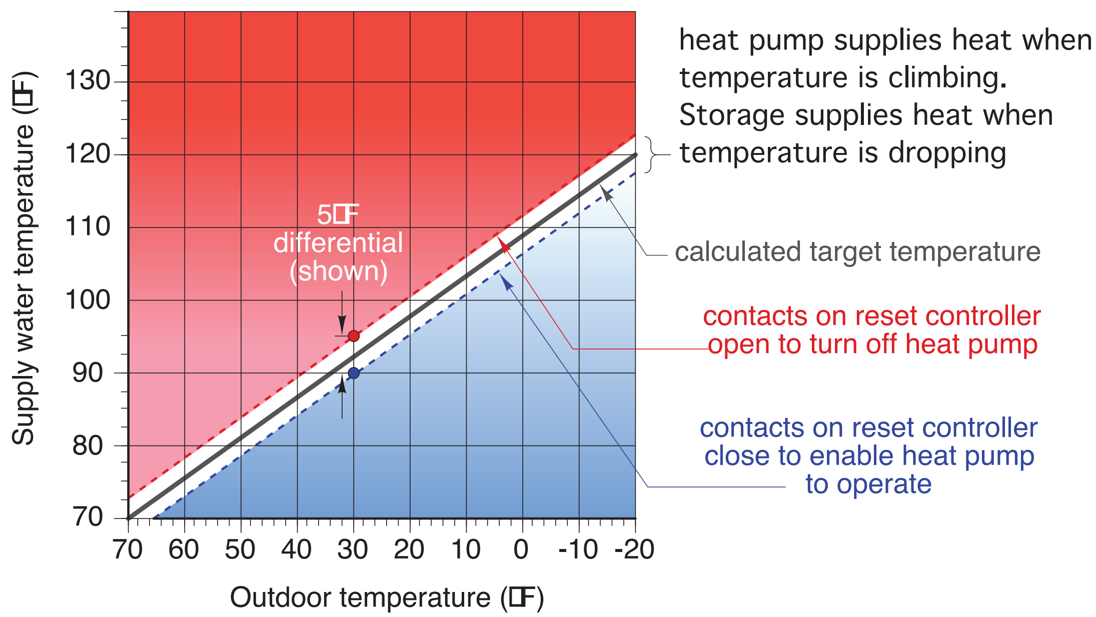
Finally, be sure the distribution circulator is sized for the combined head loss of the distribution system as well as the heat pump's condenser.

MULTI-ZONE, HEATING-ONLY SYSTEM

Whenever an on/off hydronic heat pump is used as the heat source for a zoned hydronic distribution system, a buffer tank must be used to prevent the heat pump from short cycling. The buffer tank stabilizes the system when the rate of heat generation by the heat pump is significantly different than the rate of heat dissipation by the zoned distribution system.

Figure 5-2 shows an example of a multi-zone, heating-only system with a buffer tank.

Figure 5-3



The heat pump is turned on and off by an outdoor reset controller that monitors the temperature of the buffer tank whenever their is a call for heating. Whenever the temperature of the storage tank drops below a calculated lower limit, the heat pump and its two associated circulators are turned on. When the tank reaches a calculated upper temperature limit, the heat pump and circulators are turned off. Figure 5-3 shows one concept for how the temperature of the buffer tank could be controlled using an outdoor reset controller with a fixed differential.

A wide variety of distribution system options are possible. The system shown in Figure 5-2 uses electrically operated zone valves in combination with a pressure-regulated variable-speed circulator. However, wireless thermostatic valves could also be used. If a fixed-speed circulator is used in the distribution system, a differential pressure bypass valve should be installed across the supply and return headers in the distribution system.

The buffer tank also provides hydraulic separation between the circulator on the load side of the heat pump and the variable-speed circulator in the distribution system.

The size of the buffer tank depends on the acceptable minimum run time of the heat pump and the allowed temperature differential of the tank between when the heat pump turns on and when it turns off. Appendix C gives the necessary formulas for determining the size of the buffer tank.

HEATING-ONLY, MULTIPLE-HEAT PUMP SYSTEM

Multiple heat pumps can be combined much like multiple boilers. Doing so provides improved matching between instantaneous heat generation and heating load. This, in turn, reduces the necessary size of the buffer tank. In some cases, it may even eliminate the need for a buffer tank.

The system shown in Figure 5-4 uses three heating-only heat pumps operated by a multi-stage outdoor reset controller. That controller monitors the temperature of the buffer tank and uses outdoor reset logic to determine when and how many heat pumps should be operating at any given time. The goal is to keep the temperature of the buffer tank within a suitable range for immediate use by the distribution system throughout the heating season. The staging controller can also be used to “rotate” the operating order of the heat pumps so that each one accumulates approximately the same total run time over a heating season.

A hydraulic separator is shown as the interface between the earth loop and low-temperature headers supplying the source side of the heat pumps. This allows the flow rate in the earth loop to be different from the flow rate through the headers supplying the source side of the heat pumps. With proper control, the earth loop circulator could be operated at variable speeds depending on the current source requirements of the heat pumps. The hydraulic separator also provides high-performance air and dirt separation for the earth loop and source side

Figure 5-4

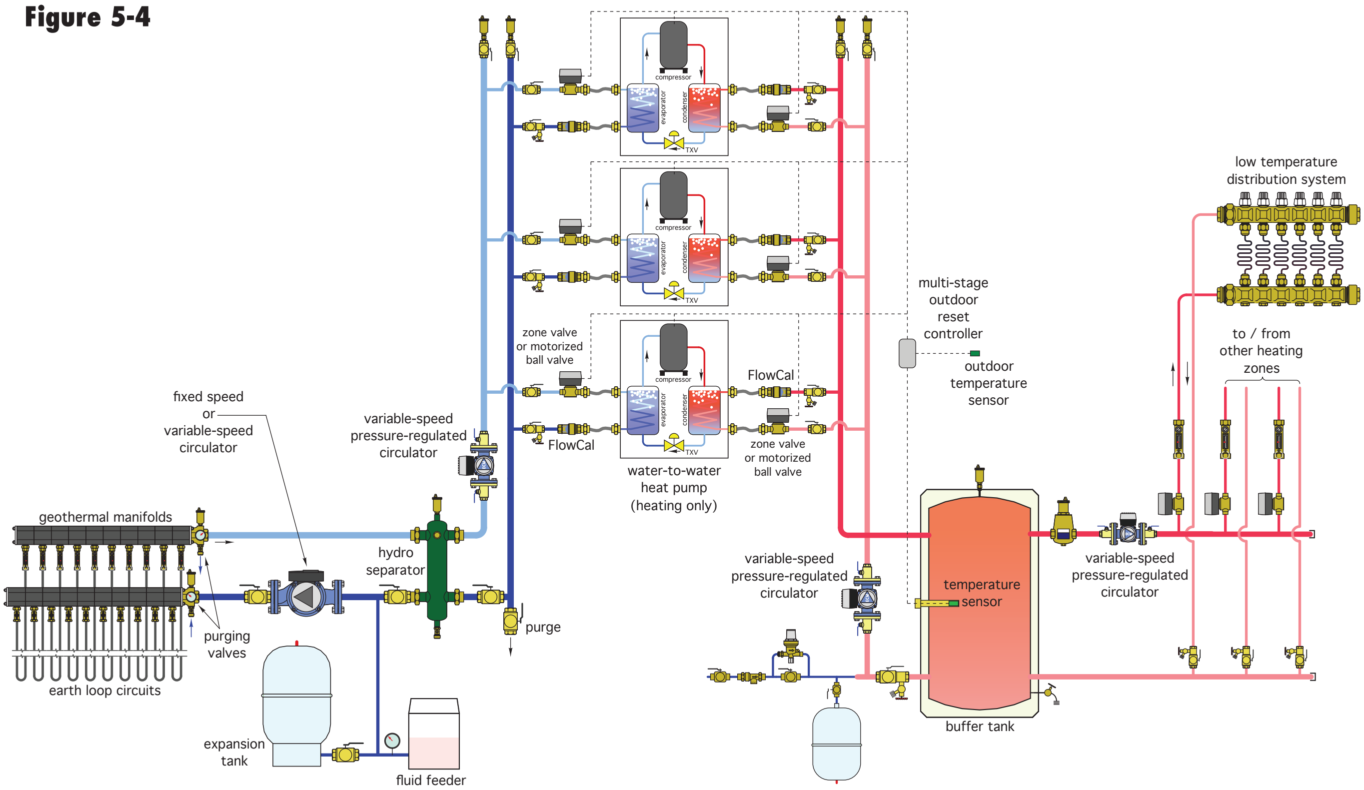
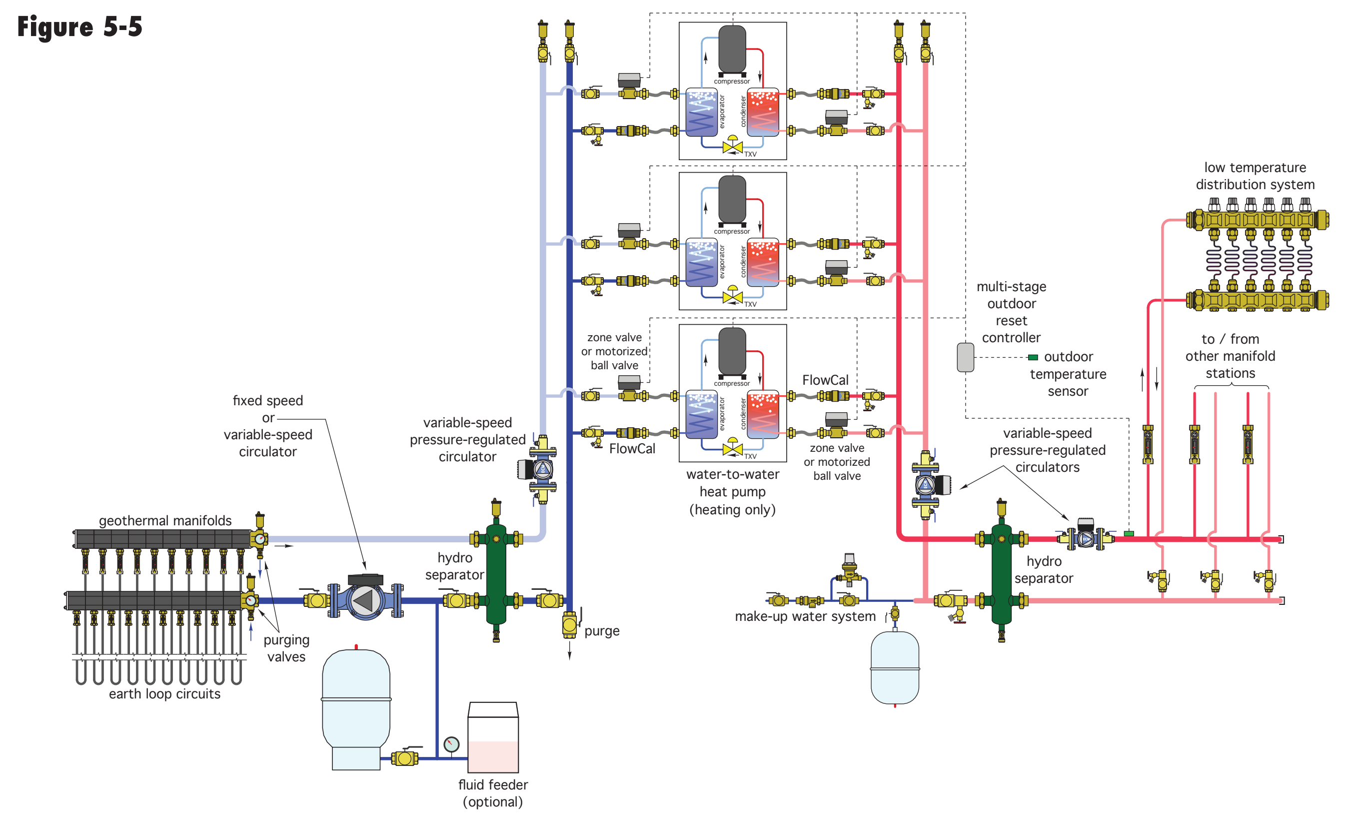


Figure 5-5



heat pump piping. Keep in mind that this piping detail could also be implemented with a fixed-speed earth loop circulator, that at some point in the future could be retrofited for variable-speed operation.

Flow through the load side of each heat pump is also controlled by a pressure-regulated variable-speed circulator set for constant differential pressure control. When a given heat pump turns on, its associated zone valves (or motorized ball valves) opens, and the speed of the circulator adjusts to maintain constant differential pressure between the headers. This approach significantly reduces pumping power requirements under partial load conditions. The headers on both the source and load side of the heat pumps should be designed for very low head loss. It is suggested that these headers be sized for a maximum flow velocity of 2 feet per second under full flow conditions.

The distribution system uses a single pressure-regulated variable-speed circulator in combination with electric zone valves.

If the distribution system operates as a single zone, or if the smallest individual zone load is close to the capacity of a single heat pump, the buffer tank shown in Figure 5-4 could be replaced by a hydraulic separator, as shown in Figure 5-5.

6. COMBINED HEATING & COOLING SYSTEMS

One of the most unique benefits of all "reversible" heat pumps is their ability to provide winter heating as well as warm weather cooling. There are many ways to "leverage" the benefit using modern hydronics technology. This section presents several templates for systems that provide both heating and cooling.

Before exploring these combination systems it is important to discuss some specifics about using chilled water for cooling purposes.

CHILLED WATER TEMPERATURES

Most hydronic heat pumps, both water-to-water and air-to-water configurations, are capable of producing chilled water in the temperature range of 40º to 60ºF. Many are capable of even lower water temperatures, in some cases even lower than 32ºF if an antifreeze solution is used. However, operating heat pumps at very low fluid temperatures will significantly lower their EER (Energy Efficiency Ratio) as well as their cooling capacity. It is seldom necessary to operate properly designed chilled water systems at supply water temperatures less than 45ºF. The higher the chilled water temperature can be, the more efficient the heat pump is. However, at supply water temperatures higher than approximately 60ºF, the ability of a chilled water terminal unit to remove moisture from the air diminishes quickly. Moisture removal from building air is known as latent cooling, and it is critical in maintaining proper comfort conditions.

CHILLED WATER TERMINAL UNITS

A "chilled water terminal unit" is any device designed to both cool and dehumidify room air by transferring both sensible and latent heat from that air into a stream of chilled water passing through the terminal unit. Moisture is removed by operating the heat exchanger portion of the terminal unit below the dewpoint temperature of the room's air. The dewpoint temperature of air is the temperature at which the air cannot absorb and hold any more moisture. When it reaches the dewpoint temperature, the air is said to be "saturated" with moisture. Any further cooling of the air results in liquid water droplets being formed on any surface that causes this cooling. While dew formation is a perfectly natural and expected condition on outside surfaces such as a lawn in early morning, it can cause very undesirable results when it unexpectedly shows up on interior building surfaces. Thus, intentional moisture removal from inside air should only occur in properly designed chilled water terminal units that contain a "drip pan" to catch the resulting condensation and route it to a suitable drain.

Figure 6-1a

Source: Spacepak

Figure 6-1b

Source: Aermec

Figure 6-1 shows some examples of currently available chilled water terminal units. They range from air handlers that are designed for concealed mounting above or below finished occupied spaces, to console units designed to be mounted on walls or ceilings. All of these terminal units are equipped with drip pans and condensate drains.

CHILLED WATER PIPING CONSIDERATIONS

Figure 6-2

Just as condensate forms on the heat exchange surfaces within chilled water terminal units, it can also form on piping, valves, circulators or any other circuit components that have a surface temperature lower than the air current dewpoint temperature. This is especially true of metal components. Figure 6-2 shows a circulator carrying conveying chilled water. Notice the condensate that has formed on the volute and flanges. Such condensate will eventually drip from the circulator. Over time, this condensate will also cause corrosion on the surface of the circulator.

Proper practice is to insulate all piping components carrying chilled water. The insulation should have a low vapor permeability. Flexible foam rubber insulation, as seen in Figure 6-3, is commonly used to prevent condensation, as well as undesirable heat gain on chilled water piping. Notice that all seams in the insulation are joined so that vapor-laden air cannot contact the piping. Other insulation materials are possible provided they are properly joined and include a vapor-tight jacket.

Figure 6-3

Certain portions of some piping components should not be insulated. The motor enclosure of a wet-rotor circulator is one example. Typically, the heat produced by the motor is sufficient to prevent condensate from forming. This is evident in Figure 6-2. The actuator assembly on zone valves or motorized ball valves should also remain uninsulated.

Caleffi GeoCal manifolds are specially designed to resist surface condensation due to potentially low

Figure 6-3a

fluid temperatures within the earth loop. This is done by incorporating an air space between the inner and out portions of the manifold. Figure 6-3a shows the effectiveness of this air space.

Polymer piping such as PEX, PEX-AL-PEX or PP-R (polypropylene) has a higher thermal resistance compared to that of metal piping, and thus is somewhat less prone to surface condensation when used for chilled water applications. However, every installation of such piping in chilled water cooling systems should be evaluated for condensation potential. Manufacturers of such piping often provide tables, formulas or spreadsheets that can be used to evaluate the surface condensation potential of the pipe based on a specific chilled water temperature and a corresponding room dry bulb temperature and relative humidity. This potential should *always* be evaluated at the combination of dry bulb temperature and relative humidity that yields the highest possible dewpoint temperature. Appendix F gives methods for determining the dewpoint temperature.

The "bottom line" with all chilled water piping is to respect the fact that condensation formation is undesirable and can quickly lead to stained ceiling surfaces, water puddles on the floor and the growth of mold and mildew. All chilled water piping must be properly protected against these conditions.

MULTIPLE-ZONE HEATING & SINGLE-ZONE COOLING

The system shown in Figure 6-4 is an extension of the system shown in Figure 5-2. It allows for multiple heating zones, along with a single zone of cooling. The latter is accomplished using an appropriately sized chilled water air handler equipped with a drip pan.

Although shown in its heating mode, the water-to-water heat pump is reversible (e.g., able to produce either heated water or chilled water on the building side of the system). The heat pump is also shown equipped with a desuperheater heat exchanger for preheating domestic water. The latter is an option offered by several

Figure 6-4

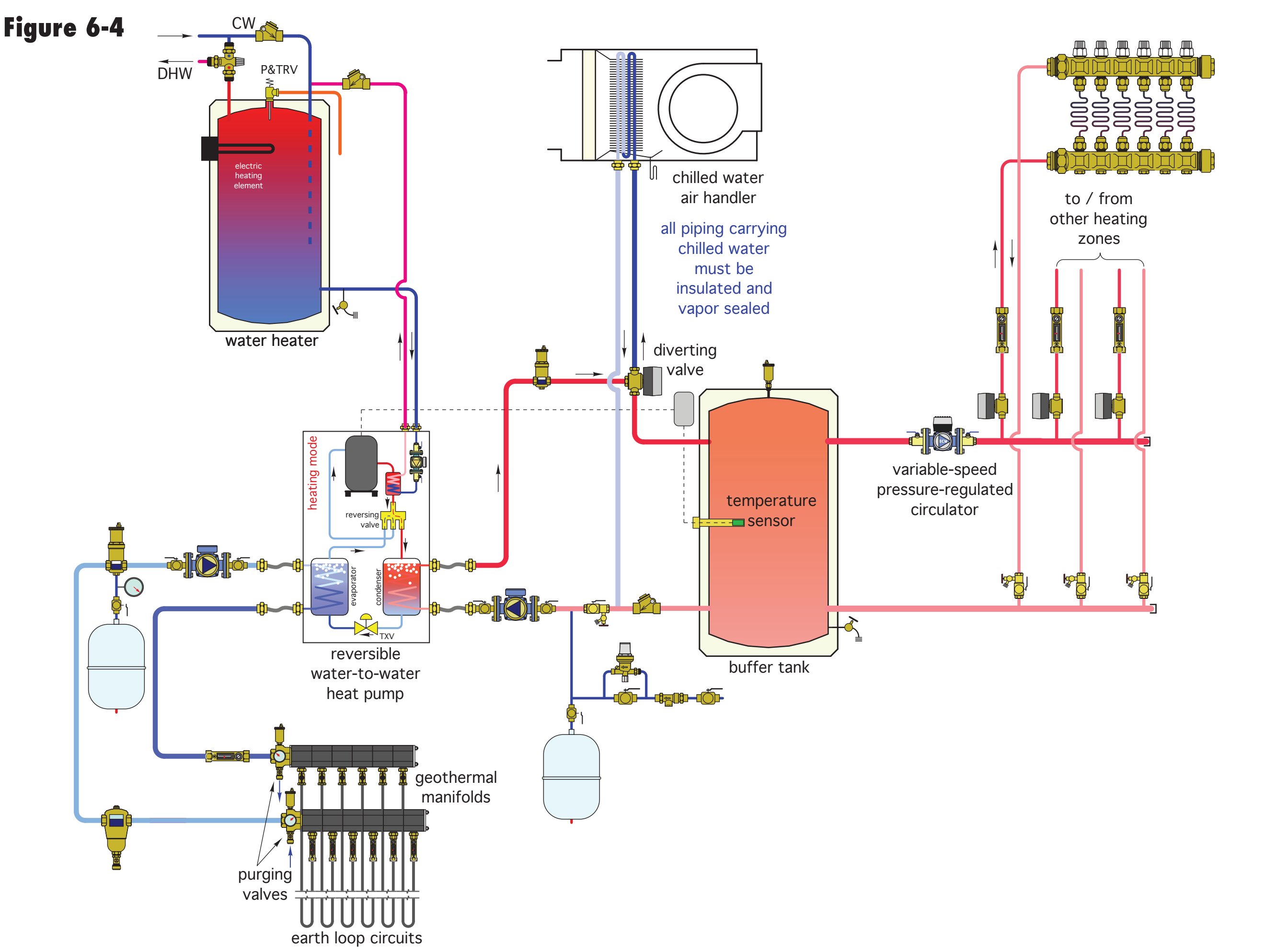
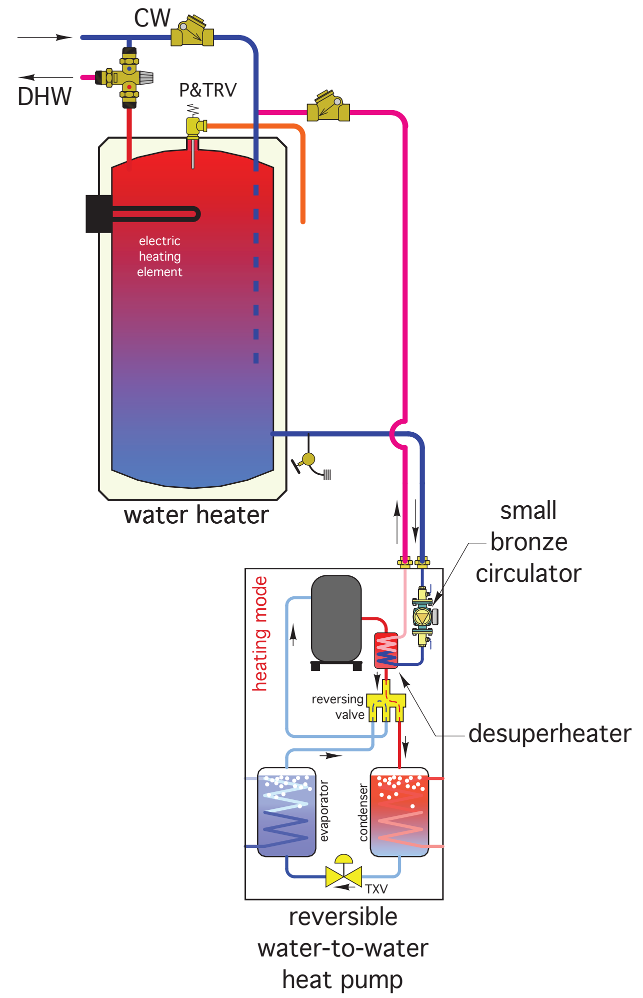


Figure 6-5



manufacturers. A closeup view of the heat pump with desuperheater and the associated piping of an electric water heater tank is shown in Figure 6-5.

The desuperheater is a refrigerant to water heat exchanger. It receives the highest temperature refrigerant gas directly from the compressor. Some of the heat contained in this hot refrigerant gas is transferred to a stream of domestic water being circulated through the other side of the heat exchanger. This causes the superheated refrigerant vapor to cool, but not to the point of condensing into a liquid. This process is called "desuperheating."

Using a heat pump with a desuperheater allows a portion of the heating output, when operating in the heating mode, to be used for domestic water preheating rather than space heating. Thus, a portion of the domestic water heating is achieved at the high COP of the heat pump, compared to a COP of 1.0 if provided by the electric heating element. When the heat pump is operating in the cooling mode, *all* the heat extracted by the desuperheater would otherwise be dissipated as "waste heat" to the earth loop or air-cooled condenser. Thus, any domestic water preheating effect achieved through the desuperheater in this mode is truly "free heating."

Heat pumps equipped with a desuperheater typically contain a small bronze circulator that moves water between a tank-type water heater and the desuperheater. This circulator usually operates whenever the compressor is operating. In some cases, its wiring can be configured to turn it off under certain operating modes.

Water from near the bottom of the water heater tank flows into the desuperheater. Water leaving the desuperheater flows back to the dip tube in the water heater. This arrangement allows the desuperheater to work with the cooler water in the tank, and thus maintains maximum heat transfer.

In the system shown in Figure 6-5, water flow on the load side of the heat pump passes through a diverter valve, which changes its routing depending on the operating mode of the system. In the heating mode, the water is passed on to the buffer tank. From there it can be used by the zoned distribution system as described for previous systems.

When the system changes to cooling mode, the diverter valve directs chilled water directly to the air handler. Because this is a *single-zone* cooling system, there is no need to pass chilled water through a buffer tank. This allows the system to be switched between heating and cooling modes quickly if necessary.

The swing check valve seen in the lower left piping to the buffer tank is there to stop any migration of chilled water toward the buffer tank.

In this type of system, the cooling capacity of the air handler must be matched to the cooling capacity of the heat pump, while allowing the chilled water supply temperature to remain in a reasonable operating range (suggested at 45° to 55°F).

MULTIPLE-ZONE HEATING & MULTIPLE-ZONE COOLING

Many of the advantages of zoning a hydronic heating system also apply to a chilled water cooling system. They include:

• Lower cost per zone compared to zoned forced-air systems.

• Allows smaller terminal units to be strategically located.

• Systems can easily control differential pressure in the distribution system relative to air-side zoning.

• Smaller diameter flexible piping is less invasive to the building structure compared to ducting.

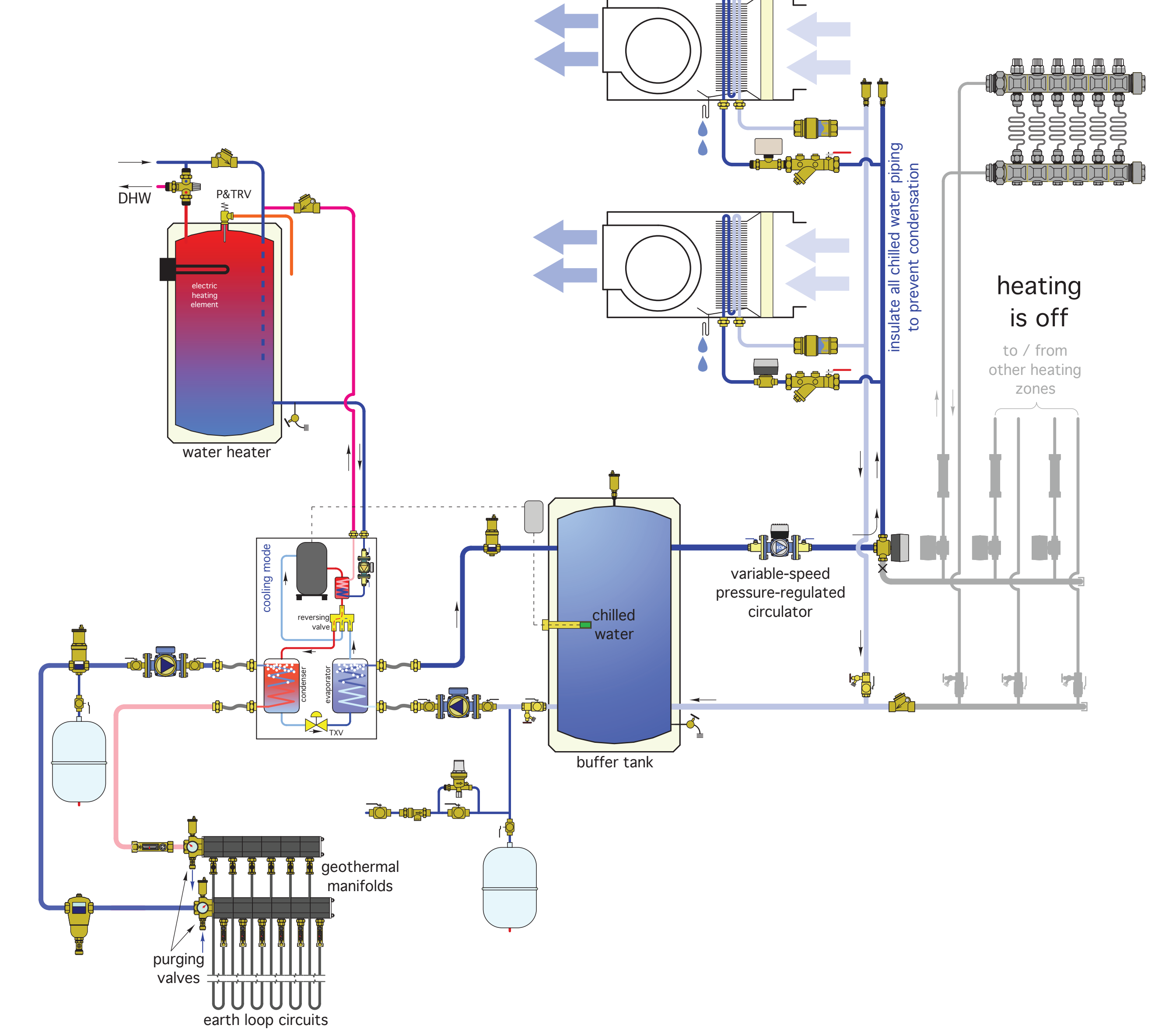
• With proper design, zoned hydronic distribution systems have significantly lower electrical power requirement compared to forced-air distribution systems.

• In some systems, radiant cooling panels or chilled beams can handle the sensible portion of the cooling load. Ventilation and latent cooling loads are handled by a forced-air subsystem. This greatly reduces the size of the necessary ducting.

Figure 6-6 shows one template for a multiple-zone heating and cooling system. In this case, the cooling mode is shown as active, while the portion of the system used for heating is shown as inactive (gray).

This system uses a single tank to buffer both the space heating and cooling distribution subsystems. During the heating mode, the heat pump maintains this tank at a suitable temperature based on outdoor reset control. During the cooling mode, the control system will maintain

Figure 6-6

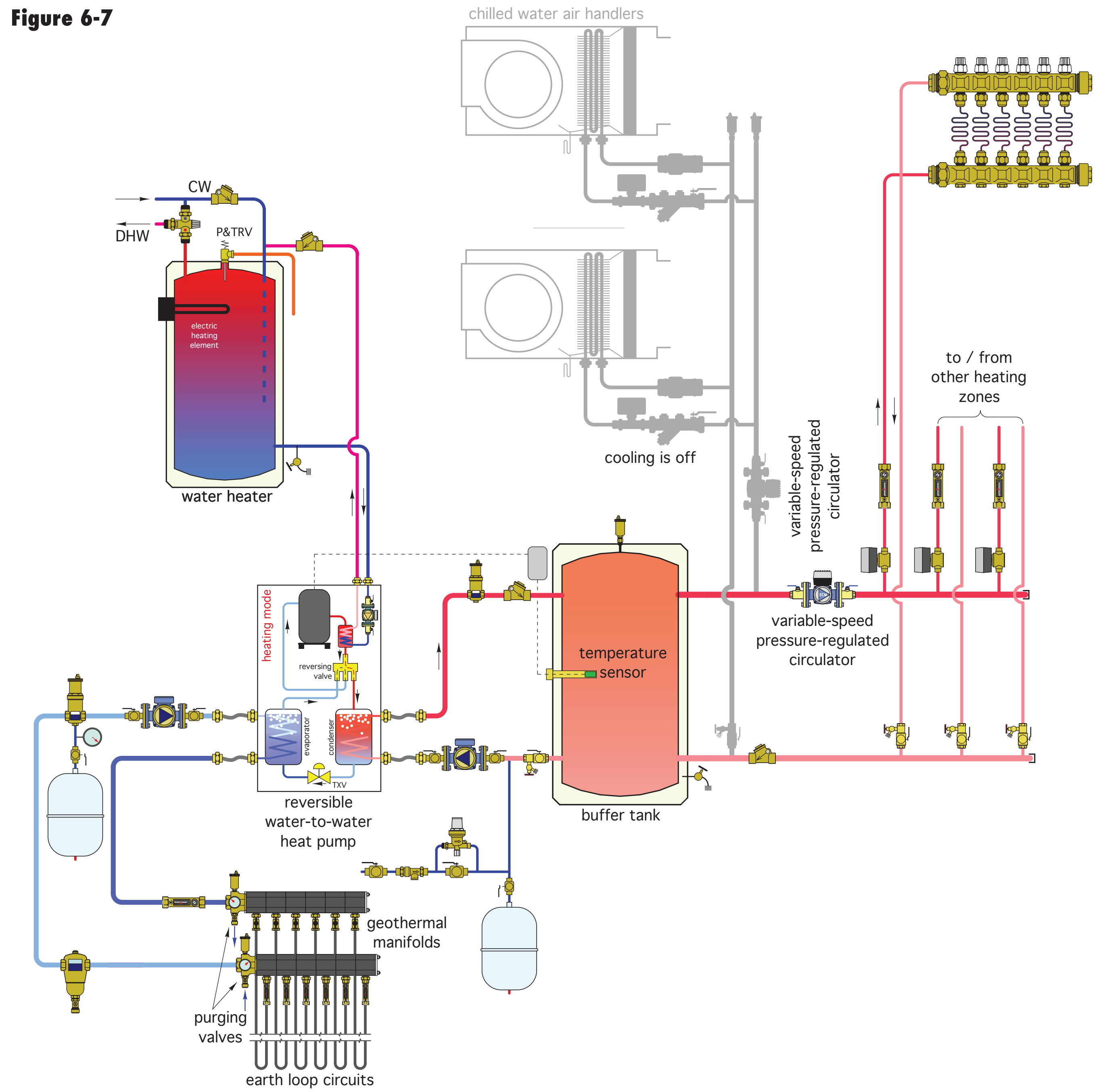


this tank between set upper and lower limits (typically not lower than 45°F and not higher than 60°F).

Because it contains chilled water, it is imperative that the buffer tank be properly insulated and vapor-sealed to prevent condensation from forming on the inner pressure vessel. Only tanks with sprayed foam insulation should be used. All seams in the tank jacket should be sealed. All piping connections should also be sealed with vapor impermeable insulation.

This system configuration is NOT recommended for installations where heating and cooling may be required within a few hours of each other. It makes little sense to warm the tank in the morning, only to have to extract all that heat and further cool the tank later that day. There are climates where morning heating followed by afternoon cooling may be required. Such situations are best handled by systems with dual buffer tanks, which will be described later in this section.

Figure 6-7



In climates where the heating season ends in later spring, and the need for cooling doesn't typically begin for several more days (or weeks), the buffer tank will eventually reach the room air temperature before having to be further cooled when warm weather arrives.

A single variable-speed pressure-regulated circulator is shown on the load side of the buffer tank. Flow leaving this circulator passes through a diverter valve, which directs it to either the heating circuits or cooling circuits. Zone valves are used on all distribution circuits. As these valves open and close, the circulator automatically adjusts speed to maintain the desired differential pressure on the distribution headers.

This configuration assumes that the flow and head requirements of the heating and cooling distribution system are similar, and thus the same circulator can provide either with no need of adjustment. If this is not the case, a separate variable-speed pressure-regulated circulator should be selected for each subsystem, as shown in Figure 6-7, which now shows the system in heating mode operation. Each circulator must be appropriately sized and set to provide the specific flow and head required within its portion of the system. This approach eliminates the need for the diverting valve.

MULTIPLE-BUFFER TANK SYSTEMS

The system shown in Figure 6-8 combines several of the design details discussed in previous systems.

The earth loop is piped through a hydraulic separator. This allows the potential for variable-speed control of the earth loop circulator depending on the thermal load created by the heat pumps. In situations where the rate of heat absorption by heat pumps operating in the heating mode equals the rate of heat dissipation by heat pumps operating in the cooling mode, flow through the earth loop can theoretically be reduced to zero. The hydraulic separator also provides efficient air and dirt separation for the earth loop and source side of the heat pumps.

Flow through the left side of each heat pump is controlled by an associated circulator equipped with an integral check valve. This circulator only operates when the heat pump is on. The integral check valve prevents reverse flow through inactive circulators.

Figure 6-8

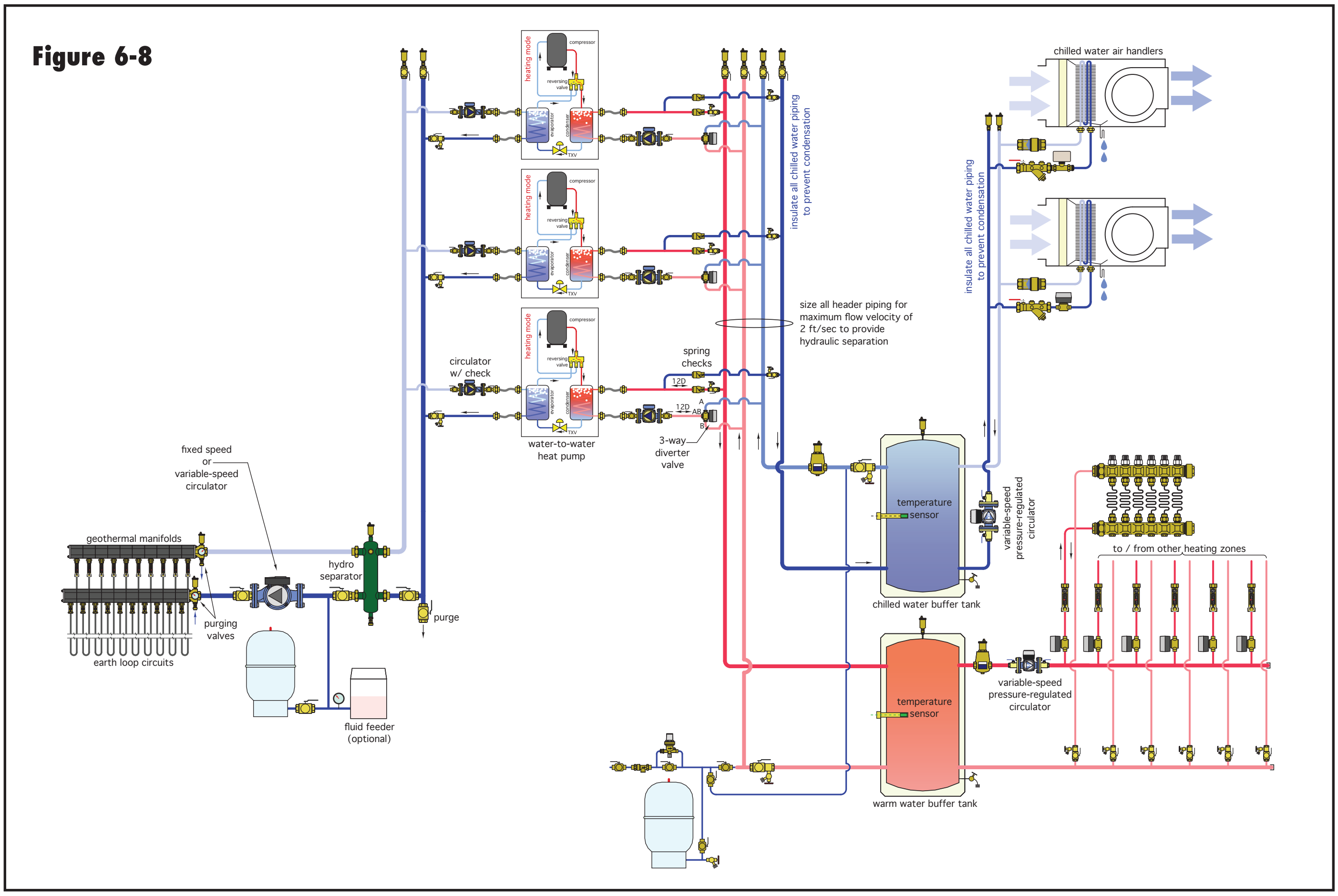
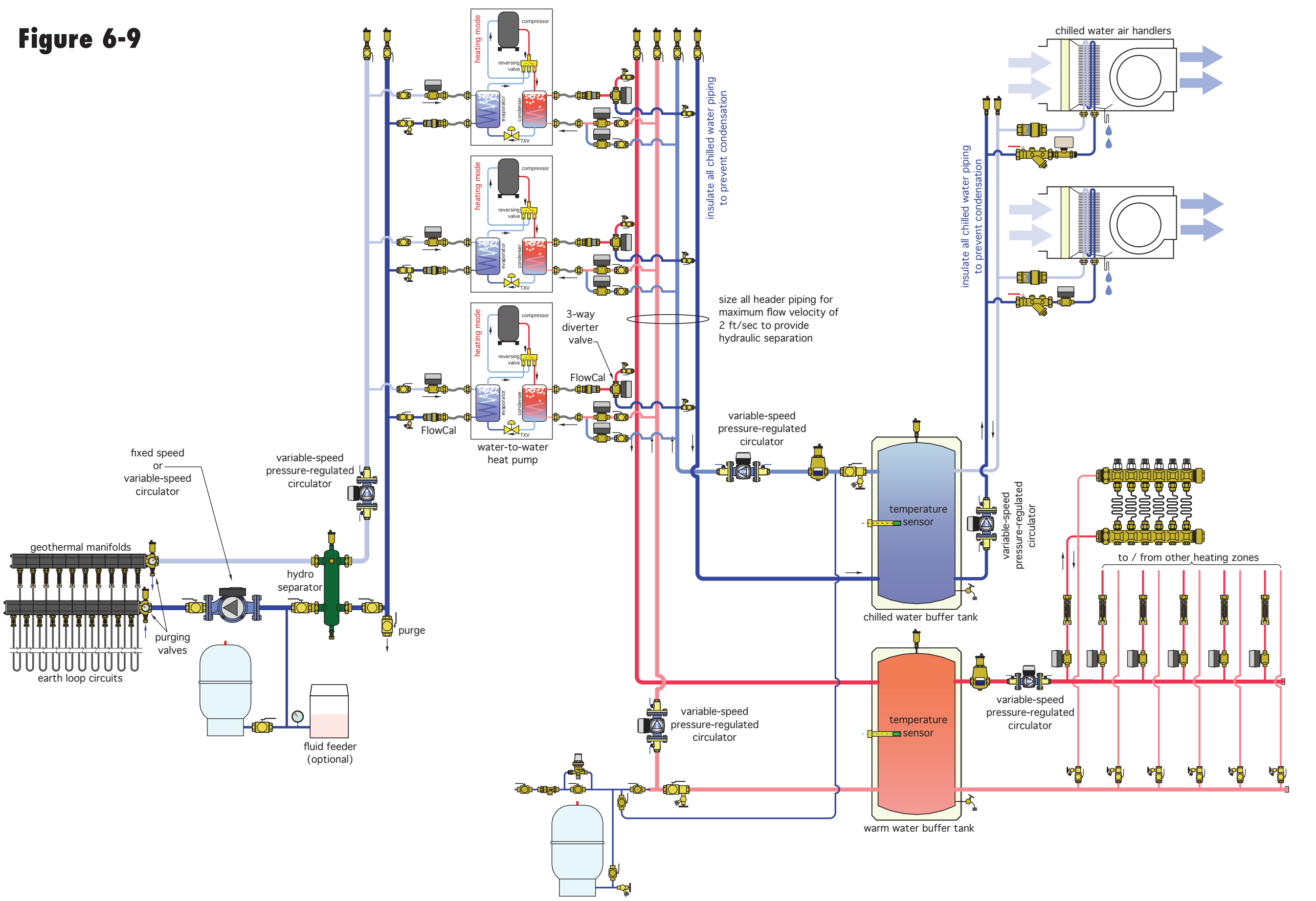


Figure 6-9



The right side of each heat pump is equipped a circulator and 3-way diverter valve. The latter would be unpowered in the heating mode (e.g., flow from the B to AB port) and powered in the cooling mode (e.g., flow from the A to AB port). This ensures that flow entering a heat pump is provided from either the hot water header or the chilled water header, but never a combination of the two. An external check valve on the piping leading away from the heat pumps further reduces any potential for heat migration. Install at least 12 diameters of straight piping upstream of the circulator, as well as on the inlet side of the check valves to reduce turbulence and possible valve chatter.

The headers leading to the buffer tanks should be kept as short as possible and generously sized (e.g., sized for a maximum flow velocity of 2 feet per second). This helps ensure good hydraulic separation between the various circulators. All piping and piping components carrying chilled water should be insulated and vapor-sealed to prevent condensation.

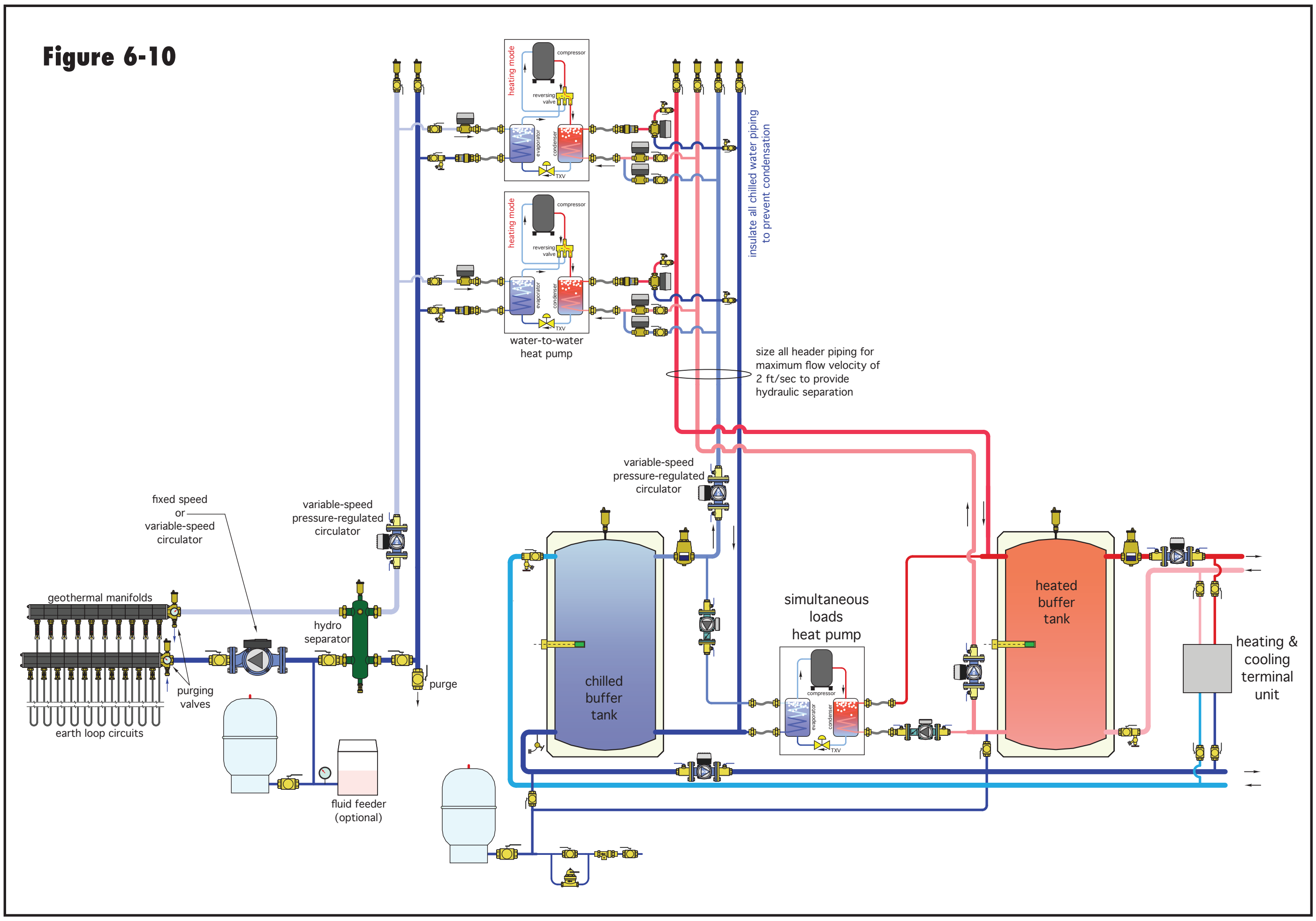
The dual buffer tanks stand ready to provide heating or cooling at any time either load may be present. This piping arrangement, in combination with proper controls, allows any of the heat pumps to be “called” to operate in either heating mode or cooling mode at any time, as required by the building load.

The buffer tanks also provide hydraulic separation between the heat pump circulators and the variable-speed pressure-regulated circulators in the distribution system. The heating and cooling distribution subsystems downstream of these buffer tanks can be designed as needed.

Note that chilled water is drawn from the lower piping connection on the chilled water buffer tank. The lower portion of this tank contains the coolest (e.g., most dense) water. Since this tank is only used for cooling, this piping maximizes its ability to deliver the lowest temperature water to the distribution system.

The system shown in Figure 6-9 is a variation on the system of Figure 6-8. It uses a combination of zone valves (or motorized ball valves) to allow or prevent flow through both the source and load sides of each pump. These valves also prevent thermal migration between the heating

Figure 6-10



and cooling portions of the piping. A motorized diverting valve determines if the output of the heat pump is routed to the heating or cooling side of the system. Variable-speed pressure-regulated circulators modulate flow through both the source and load side headers based on the current flow needs of the heat pump array. The earth loop piping and distribution side piping are shown the same as in Figure 6-8, but could be designed in many alternative ways depending on the needs of the building.

The systems shown in Figures 6-8 and 6-9 can be further expanded as shown in Figure 6-10. A non-reversible water-to-water heat pump has been placed between the two buffer tanks. When operating, it simultaneously cools the chilled water buffer tank while adding heat to the heated water buffer tank. This operating mode would occur only when there is simultaneous demand for heating and cooling.

The "effective COP" of the simultaneous loads heat pump is the ratio of the total desirable heat transfer effect divided by the total electrical input. It can be calculated using Formula 6-1.

Formula 6-1

$$COP_{effective} = \left(2 \times COP_{hp}\right) - 1$$

Where:

$COP_{effective}$ = the effective COP of the simultaneous loads heat pump (e.g., the ratio of the desirable thermal transfer divided by electrical input)
COP_{hp} = the current COP of the heat pump

For example: Assume the heat pump transferring heat between the chilled water and heated water buffer tank is operating at a COP of 4.0. Under this condition, its effective COP (as defined by Formula 6-1) would be:

$$COP_{effective} = \left(2 \times 4\right) - 1 = 7.0$$

This means that the heat pump is creating beneficial heat transfer at a rate 7 times higher than the rate of electrical energy transfer to operate it. This is a profound advantage that can be realized when simultaneous heating and cooling are necessary.

Implementing this strategy requires a control system that senses when both buffer tanks need to be conditioned (e.g., heated or cooled). When such conditions are present, the heat pump between the tanks is turned on, and the rate of change of water temperature in the tanks is monitored. If necessary, one or more of the other heat pumps are operated to make up a difference in the required rates of heating or cooling.

If the entire system is operating in heating mode, as it might during mid-winter, the heat pump between the tanks would remain off, and the other heat pumps would be staged on in the heating mode as necessary. Similarly, if the entire building is in cooling mode, the heat pump between the buffer tanks would remain off, while the upper heat pumps will be operated in staged cooling.

The terminal units represented in Figure 6-10 are generic heating and cooling units. They could be air handlers or fan coils with both heated water and chilled water coils. They might also represent devices such as chilled beams, or the combination of radiant panels and air-handlers.

7. SPECIALTY APPLICATIONS

The versatility of hydronic heat pumps allows them to be used in many unique applications along with other heat sources, or for loads other than building heating and cooling. This section examines several unique combinations.

HEATING-ONLY SYSTEM WITH HEAT PUMP & MOD/CON BOILER

Although it is generally true that hydronic heat pumps can be sized for the full design heating load of a building, there may be circumstances where it is impractical to cover every possible load scenario.

One example is a building in which significant and sudden demands for domestic hot water are likely. Such loads can easily exceed the design space heating load of the building, but may only be present for short durations.

Another example would be snowmelting applications. Again, the load, when present, could be intense, but it may only occur occasionally, and often with little advanced warning.

Figure 7-1

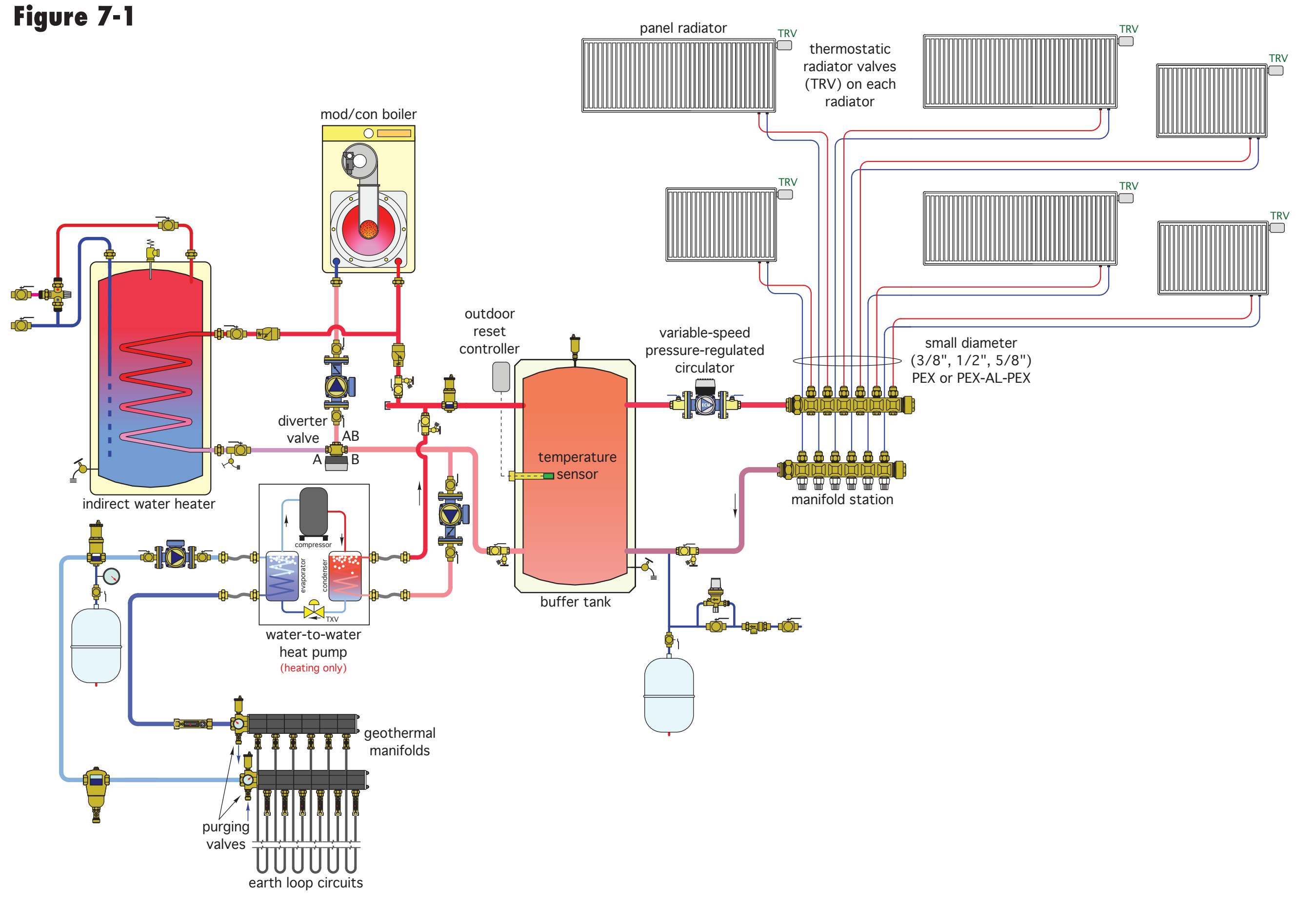
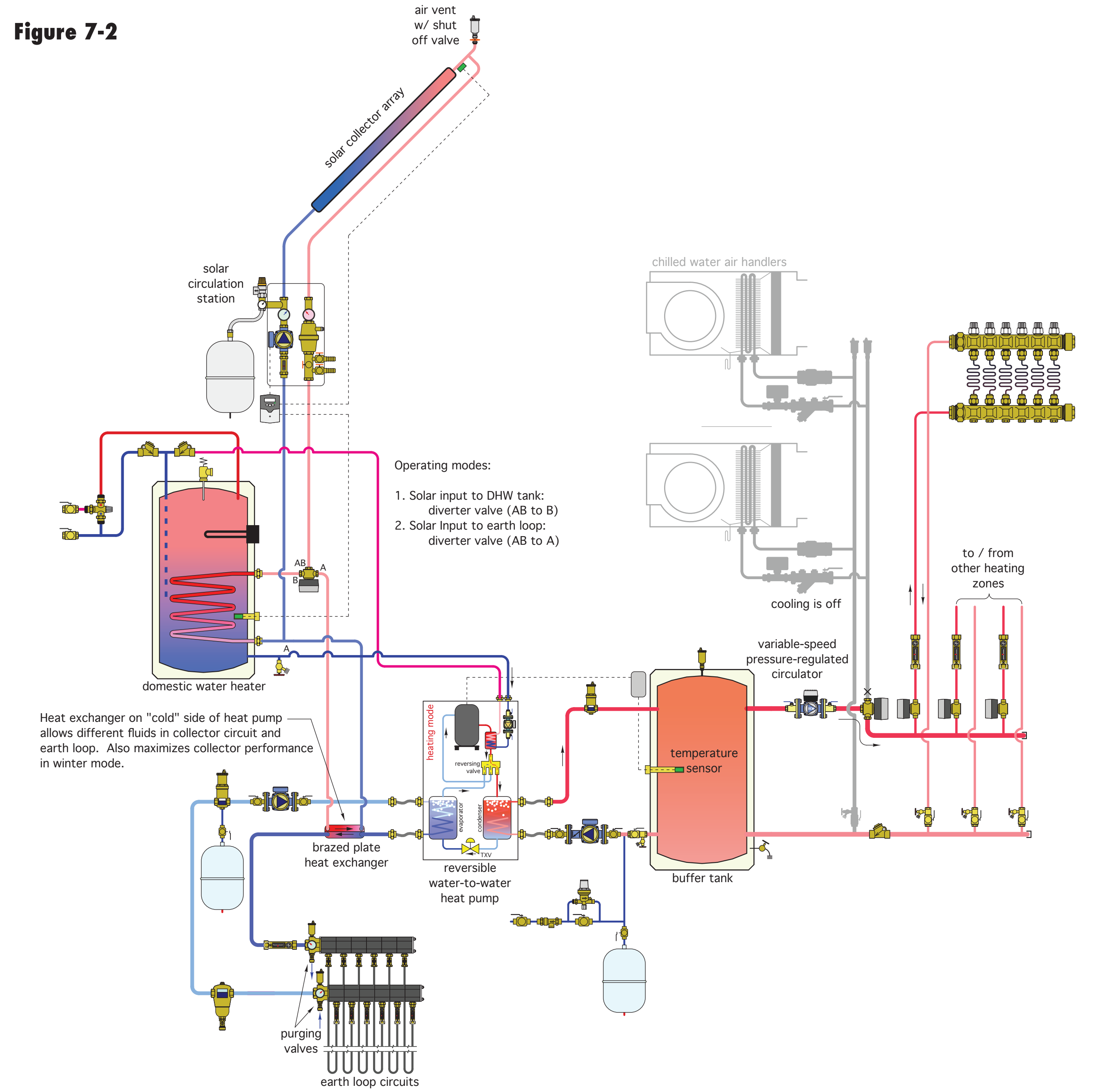


Figure 7-2



Still another possibility is where space or land requirements limit the installed heat pump capacity relative to the design load, and thus supplemental heating is needed.

Finally, having a "backup" heat source always provides better assurance of uninterrupted heating for critical load situations.

These situations can be handled by a combination heat pump/boiler system. An example of such a system using a geothermal water-to-water heat pump and modulating/condensing boiler is shown in Figure 7-1. In this case, it supplies several independently controlled panel radiators using a manifold-based distribution system.

The mod/con boiler and heat pump are each connected to the headers leading to the buffer tank. Each has its own circulator with integral check valve. Either heat source can operate by itself, or both could operate simultaneously. The header piping should be kept short and sized for a maximum flow velocity of 2 feet per second to provide hydraulic separation between the circulators.

Proper control is critical with this system. For example, if a load such as domestic water heating requires a water supply temperature over the nominal 120ºF limit of the heat pump, the heat pump needs to either remain off while this load is operating, or be isolated from the portion of the system operating at higher water temperature. One way to do this is shown in Figure 7-1. During the call for domestic water heating, the boiler is temporarily removed from space heating portion of the system by the 3-way diverter valve. During this time, the heat pump could continue to supply space heating. Ideally, all loads would operate at water temperatures that can be attained by either the heat pump or boiler.

GEOTHERMAL HEAT PUMP COMBINED WITH SOLAR THERMAL SUBSYSTEM

The combined use of solar thermal collectors and geothermal heat pumps is sure to be a growing market in the years ahead. There are many ways to combine these technologies, depending on the equipment, the nature of the load and the climatic conditions at the site.

Figure 7-2 shows a relatively simple combination involving a standard solar domestic water heating system and a reversible water-to-water geothermal heat pump that supplied zoned heating and cooling.

The solar collectors can operate in two modes:

- Supplying heat to the coil in the solar storage tank
- Supplying heat to the earth loop

Each mode has advantages at times. For example, when supplying heat to the earth loop during the heating season, the operating temperature of the collectors will typically be quite low. By late winter, it may even be lower than the outside air temperature. This allows the collectors to operate at high efficiencies. It may also allow the collectors to gather useful heat on marginal solar days that would otherwise not be collected if the collectors were operating at the higher temperatures required for domestic water heating.

In some applications, where the cooling load is not long in duration, the earth loop could also serve as a heat dump for the collector array, once the solar storage tank has reached a maximum temperature.

During warmer weather, the diverter valve routes the collector flow through the heat exchanger coil within the solar storage tank. In this mode, the solar subsystem is isolated from the earth loop and functions the same way as it would in a stand-alone solar water heating application.

If the heat pump is equipped with a desuperheater for domestic water heating, it can be piped to the tank as shown. Normally, the desuperheater would provide heat input to the tank whenever the heat pump's compressor is operating. However, in this application, the system's controls should monitor the temperature within the solar storage tank and turn off the desuperheater circulator if the water temperature approaches a level where the cooling performance of the heat pump is being adversely affected.

Another possible mode is operating the collectors during summer or early fall to warm the soil and thus boost the heat pump's heating performance in early fall. Although the concept has validity, the results are highly dependent on site specifics, such as the nature of the water table and specifics of the cooling load. A relatively high water table would act as an essentially infinite heat sink, especially if the underground water is flowing. This would likely dissipate any heat added by the solar collectors. This operating mode would also only make sense in situations where no cooling is present, or after the cooling season is completed. At present, it is difficult to speculate on the potential performance of such a mode.

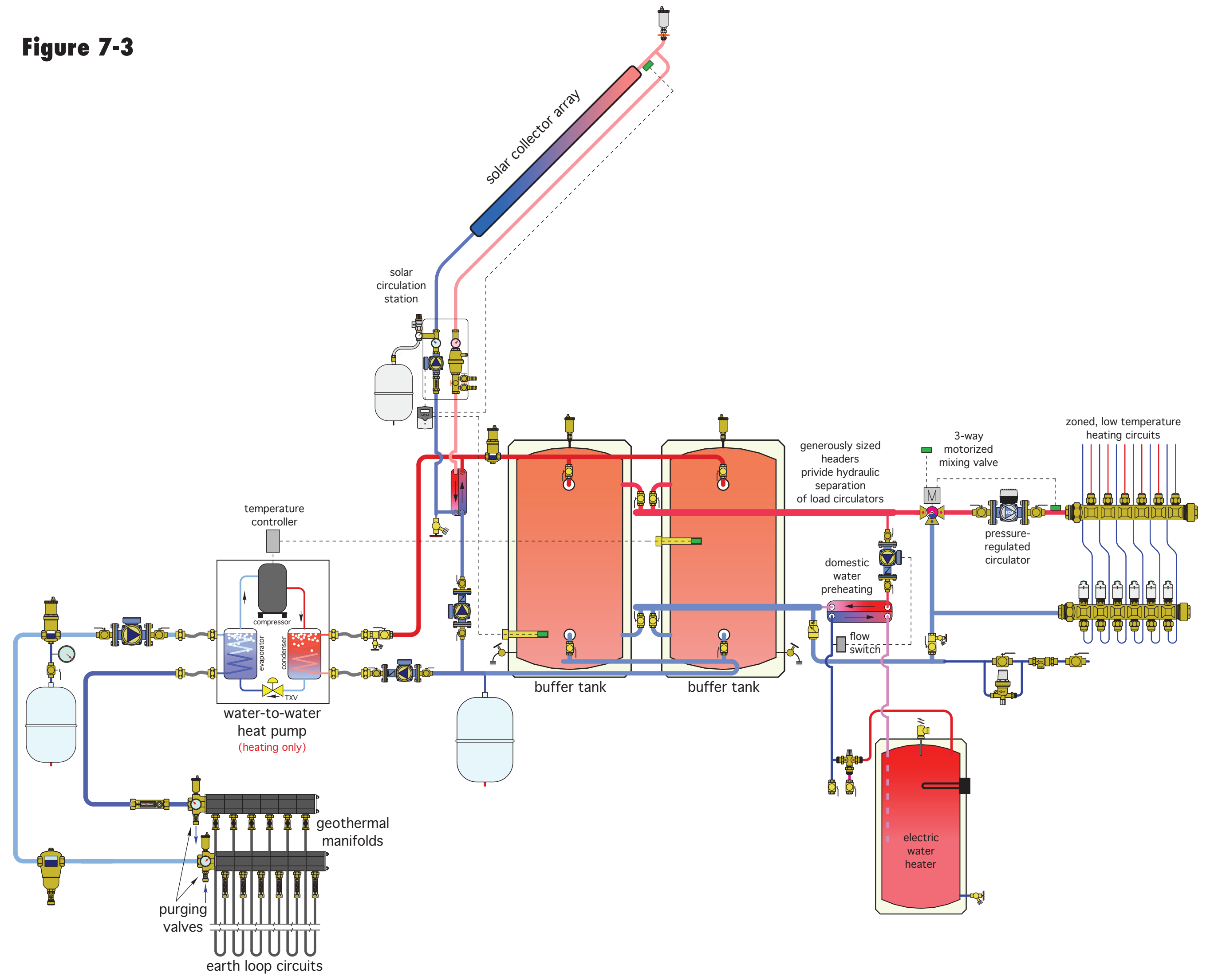
Another possible combination of solar collectors with a geothermal water-to-water heat pump is shown in Figure 7-3.

During sunny weather, the antifreeze-based solar collector array transfers heat to the buffer tank(s) through the flat plate heat exchanger. The heat pump could be operated as necessary to boost the buffer tank temperature to a useful level for space heating and domestic hot water. The latter is "preheated" using an external stainless steel heat exchanger. A flow switch in the cold water piping supplying this heat exchanger closes whenever there is a demand for hot water. This turns on a very small circulator that immediately creates flow of water from the storage tank through the primary side of the heat exchanger. The domestic water flowing through the other side of the heat exchanger is instantaneously heated to within a few degrees of the tank temperature. It then flows to the inlet of a conventional electric water heater where its temperature can be boosted if necessary. This arrangement eliminates the need for a heat exchanger inside the tank. It also allows for easy servicing or replacement of the external heat exchanger if necessary.

SYSTEMS USING OFF-PEAK THERMAL STORAGE

Many electric utilities now offer "time-of-use" electrical rates. The cost of electricity is significantly lower during low demand ("off-peak") periods, such as from 11:00 p.m. to 7:00 a.m., as well as on weekends and holidays. However, the rates for electrical energy used during the higher demand ("on-peak") periods are often higher than

Figure 7-3



non-time-of-use rates. The incentive for offering these rates is to help level the utility's demand curve (e.g., shifting more of the demand to lower demand periods). In the long term, this reduces the need for the utility to acquire additional generating capacity.

It is possible to take advantage of such utility rates using hydronic heat pumps. The concept is simple: Operate the heat pump during the off-peak periods, and store the resulting heat in a well-insulated tank for use during the subsequent on-peak periods. If the system is designed to acquire and store *all* the energy needed during the subsequent on-peak period, it is called a "full-storage system." If it only stores part of the thermal energy needed, it is called a "partial storage system." Both approaches have been successfully implemented. The best choice depends on the relative cost of the systems as well as the on-peak/off-peak rate differential.

Figure 7-4 shows one example of how a water-to-water geothermal heat pump could be configured for such a system.

This system also shows the possibility of using a wood gasification boiler as an alternative heat source for the storage tank. Heat generated by this boiler could supplement, or at times replace, heat supplied from the heat pump.

Because the wood gasification has the potential to heat the storage tank to temperatures significantly higher than the operating range of the heat pump, the system control should only allow the heat pump to operate when the tank temperature is slightly below the maximum allowed supply water temperature of the heat pump.

A distinct difference between this system and those discussed previously, is the large well-insulated pressure-rated thermal storage tank. In most residential applications,

Figure 7-4

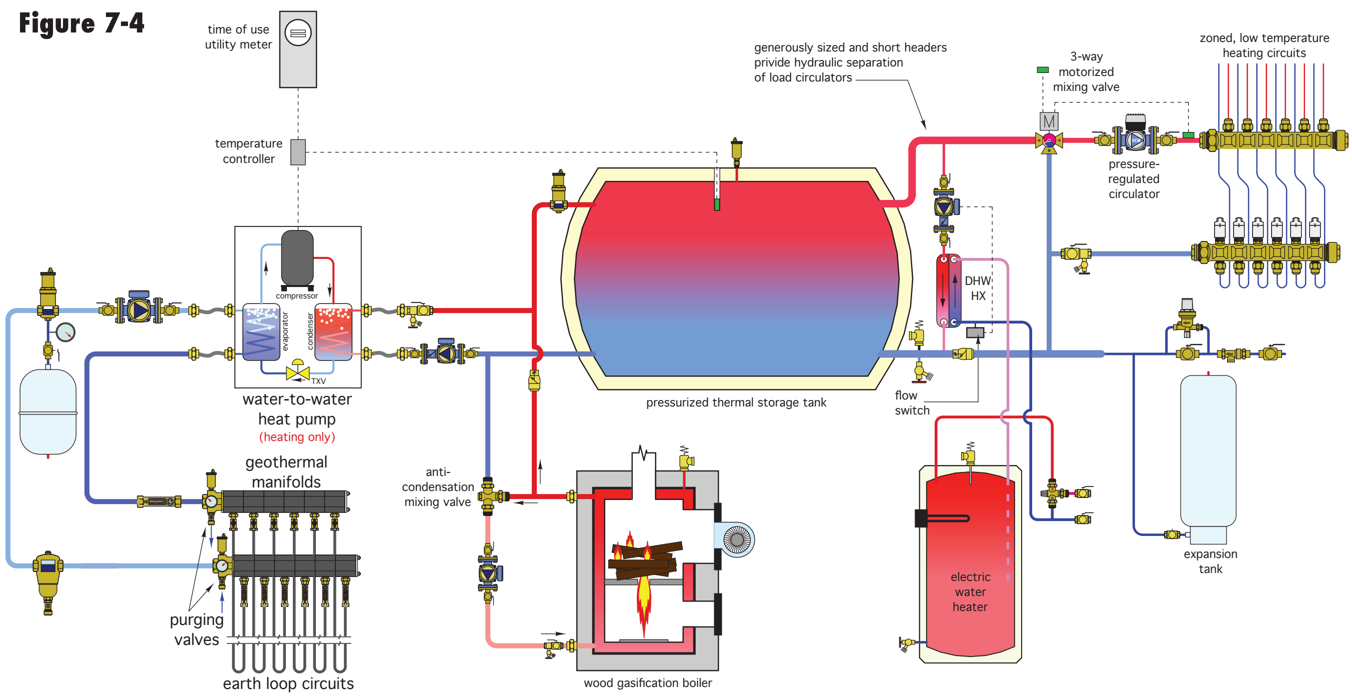
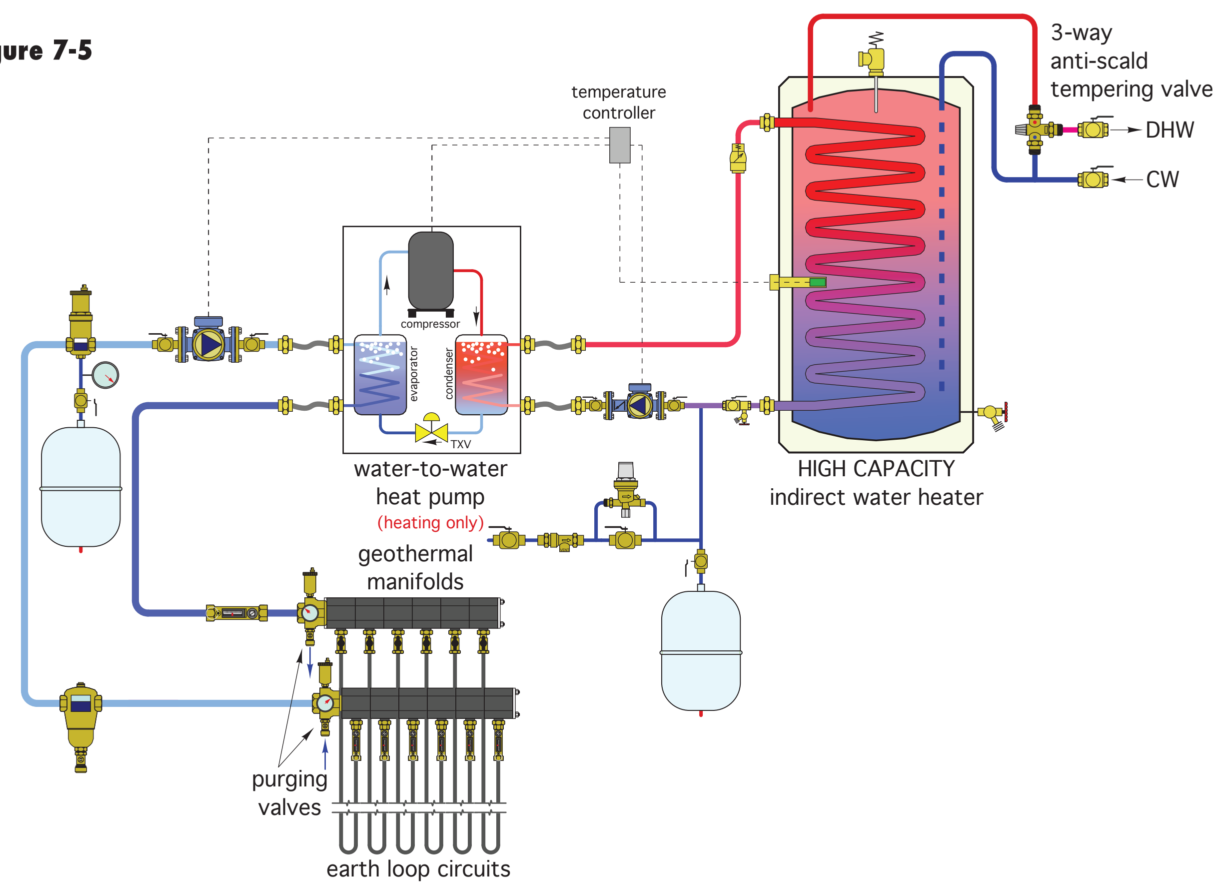


Figure 7-5



this tank will have a volume of at least several hundred gallons. In some cases, it may be as large as 500 to 1000 gallons. Because the tank adds a large volume of water to the closed loop system, the expansion tank must be significantly larger than tanks used in typical residential systems.

The specific tank size depends on the temperature range through which the tank can be cycled during the off-peak period. For example, some water-to-water heat pumps are capable of achieving supply water temperatures as high as 145ºF. Some hydronic distribution systems can deliver design output at supply water temperatures as low as 90ºF. If such a heat pump were combined with such a distribution system, the working temperature range of the storage tank, on a design load day, would be 145 - 90 = 50ºF. The storage tank could then be sized based on this temperature range and the total Btus to be stored for the on-peak period. However, if a heat pump with an upper supply temperature range of 120ºF were combined with a distribution system requiring a minimum water temperature of 95ºF, the operating temperature range of the tank would only be 120 – 95 = 25ºF. Because the latter temperature range is only half that of the first, the volume of the storage tank would have to be *doubled* to store the same amount of heat.

The following example illustrates how the volume of such a storage tank could be determined.

Example: Assume a house has off-peak rates available from 11:00 p.m. to 7:00 a.m. On a design day, the house looses 28,000 Btu/hr when it is 0ºF outside. The storage tank will be heated by a heat pump capable of heating the tank to an upper temperature of 125ºF. The minimum usable temperature of the distribution system at design load is 90ºF. Assume the *average* outside temperature during the on-peak period will be 10ºF. Determine the necessary storage tank size for a full storage system.

Solution: Heat for the 16-hour "on-peak" period must be stored during the 8-hour off-peak period. The first step in calculating the amount of heat storage required is to determine the building heat load coefficient:

$$UA_{building} = \frac{28{,}000\,Btu/hr}{(70^{\circ}F - 0^{\circ}F)} = 400\frac{Btu}{hr\cdot^{\circ}F}$$

The house's heating load when the outdoor temperature is 10ºF is thus:

$$Q = 400\frac{Btu}{hr\cdot^{\circ}F}(70^{\circ}F - 10^{\circ}F) = 24{,}000\,Btu/hr$$

Thus, the amount of heat required for a 16-hour on-peak period is:

$$H = (24{,}000\,Btu/hr)16hr = 384{,}000\,Btu$$

The tank volume needed to absorb this amount of heat with a temperature range of (125 - 90) = 35ºF is:

$$v = \frac{H}{8.33(\Delta T)} = \frac{384{,}000}{8.33(125-90)} = 1317\,gallons$$

This is a relatively large volume. A storage tank in the range of 1000 to 1500 gallons would likely be chosen depending on local availability, placement constraints within the building and cost.

The storage tank must be well-insulated. A minimum of R-20 insulation is suggested on all tank surfaces, assuming the tank will be located within heated space.

The storage tank provides excellent buffering for the highly zoned heating distribution system. The 3-way motorized mixing valve operates on outdoor reset logic and protects the low-temperature distribution system from potential high water temperatures in the storage tank due to operation of the boiler.

Domestic water is "preheated" using an external stainless steel heat exchanger. A flow switch in the cold water piping supplying this heat exchanger closes whenever there is a demand for hot water. This turns on a very small circulator that immediately creates a flow of water from the storage tank through the primary side of the heat exchanger. The domestic water flowing through the other side of the heat exchanger is instantaneously heated to within a few degrees of the tank temperature. It then flows to the inlet of a conventional electric water heater where its temperature can be boosted if necessary. This arrangement eliminates the need for a heat exchanger inside the tank. It also allows for easy servicing or replacement of the external heat exchanger if necessary.

Although not shown in Figure 7-4, hydronic heat pumps operating in cooling mode could also take advantage of time-of-use rates. The heat pump would lower the temperature of the storage tank into the range of 36º to 40ºF during the off-peak period. The stored chilled water would then be distributed through suitable terminal units during the following day. As with all chilled water applications, the storage tank and all piping components conveying chilled water must be insulated and vapor-sealed to prevent condensation.

DOMESTIC WATER HEATING

Figure 7-5 shows one system template for dedicated domestic water heating using a non-reversible water-to-water geothermal heat pump. The load side of the heat pump is connected to the internal heat exchanger in the high-capacity indirect water heater.

This system configuration requires a heat pump that can produce a supply water temperature at least 5ºF higher than the maximum domestic hot water temperature required. For example, if the maximum expected domestic hot water temperature is 120ºF, the heat pump must be capable of producing supply water temperatures of at least 125ºF.

It is also imperative to select a storage tank with the largest possible internal heat exchanger. The designer should also verify that the tank's heat exchanger can transfer heat to the domestic water at a rate equal to or greater than the maximum heat output of the heat pump, and at a time when the domestic water in the tank is at its maximum expected temperature. Failure to meet these constraints will result in marginal domestic water heating, frequent cycling of the heat pump or safety shutdown of the heat pump due to unacceptably high refrigeration pressure.

8. FILLING & FLUSHING EARTH LOOPS

Just as filling and flushing a hydronic distribution system is vital to its proper performance, so is filling and flushing the earth loop of a water source heat pump. This section shows how to fill and flush two types of earth loops: those in which earth loop circuits are individually valved, and those without valves. Keep in mind that specific hardware devices such as earth loop circulation stations can also affect the way in which a given system is filled and flushed.

During construction, there are often opportunities for dirt and other contaminants such as sawdust and insects to find their way into the earth loop piping. This debris needs to be removed in a way that does not send it into the heat pump or the earth loop circulators.

A forced stream of water is the preferable material for flushing debris from the earth loop piping. The general procedure for flushing is as follows:

A) Fill and flush the buried portions of the earth loop.

B) Fill and flush the interior piping components of the earth loop (interior piping and heat pump heat exchanger).

C) Simultaneously purge both the exterior and interior portions of the earth loop.

Once this flushing has been accomplished, the necessary quantity of antifreeze (if used) can be added to the earth loop.

DETERMINING PURGING FLOW RATE AND HEAD REQUIREMENTS

Most earth loops contain multiple parallel flow paths. This reduces the head loss of the overall earth loop while providing sufficient pipe surface area for proper heat transfer.

A "valved" earth loop provides at least one easily accessible isolation valve on each parallel circuit. A "non-valved" earth loop does not provide these valves. Both valved and non-valved earth loops can be successfully purged. However, the required equipment and procedures are significantly different.

Experience has shown that a minimum flow velocity of 2 feet per second is necessary to consistently carry air and low-density dirt particles along piping that may be oriented vertically, horizontally or at any arbitrary angle. Thus, it is necessary to establish and maintain a flow rate within each earth loop circuit being purged that ensures this flow velocity is maintained. Larger or higher-density particles, such as pebbles, will not necessarily be moved along piping operating at this flow velocity. Special care should be taken during installation to keep larger solid contaminants out of piping.

The table in Figure 8-1 shows the minimum required flow rates for achieving a flow velocity of 2 feet per second in the DR-11 HDPE 3608 tubing commonly used for earth loop circuits.

Figure 8-1

Tubing size	Min. purge flow rate (gpm)
¾" DR-11 HDPE tubing	3.6
1" DR-11 HDPE tubing	5.7
1.25" DR-11 HDPE tubing	9

Use Formula 8-1 to determine the minimum purging flow rates needed for a flow velocity of 2 feet per second in tubing materials or sizes other than those listed in Figure 8-1.

Formula 8-1

$$f_{min} = 4.896(d_i)^2$$

Where:

f_{min} = minimum flow rate needed to achieve 2 ft/sec flow velocity (gpm)

d_i = exact inside diameter of tubing (inch)

Keep in mind that these are the *minimum* acceptable flow rates for purging, and that these flow rates must be maintained within *each* parallel earth loop circuit that is being purged at a given time. Thus, if an earth loop contained five (non-valved) parallel circuits of 1-inch DR-11 HDPE piping, the minimum purging flow rate for the earth loop would be 5 x 5.7 gpm = 28.5 gpm. This is a substantial flow rate which requires a pumping source significantly more powerful than the earth loop circulator.

Once the minimum purging flow rate is determined, the corresponding head loss of the earth loop should be calculated. This is found by combining the head loss of the longest earth loop circuit, along with an estimated head loss for the header piping.

Formula 8-2 can be used to estimate the head loss of DR-11 HDPE tubing operating with cold water. The corresponding values of R are given in Figure 8-2.

Formula 8-2

$$H_{L/100'} = R(f)^{1.75}$$

Where:

$H_{L/100'}$ = head loss of piping (feet of head per 100 ft of tubing)

R = number from table in Figure 8-2

f = flow rate (gpm)

Figure 8-2

tubing	R
¾" DR-11 HDPE tubing	R = 0.269
1" DR-11 HDPE tubing	R = 0.0939
1.25" DR-11 HDPE tubing	R = 0.0316
1.5" DR-11 HDPE tubing	R = 0.0168
2" DR-11 HDPE tubing	R = 0.0059

Example: Determine the head loss of 900 feet of ¾-inch DR-11 HDPE tubing operating with cold water at a flow rate of 4 gpm.

Solution: The head loss of the tubing per 100 feet of length is found using Formula 8-2 with the value of R = 0.269:

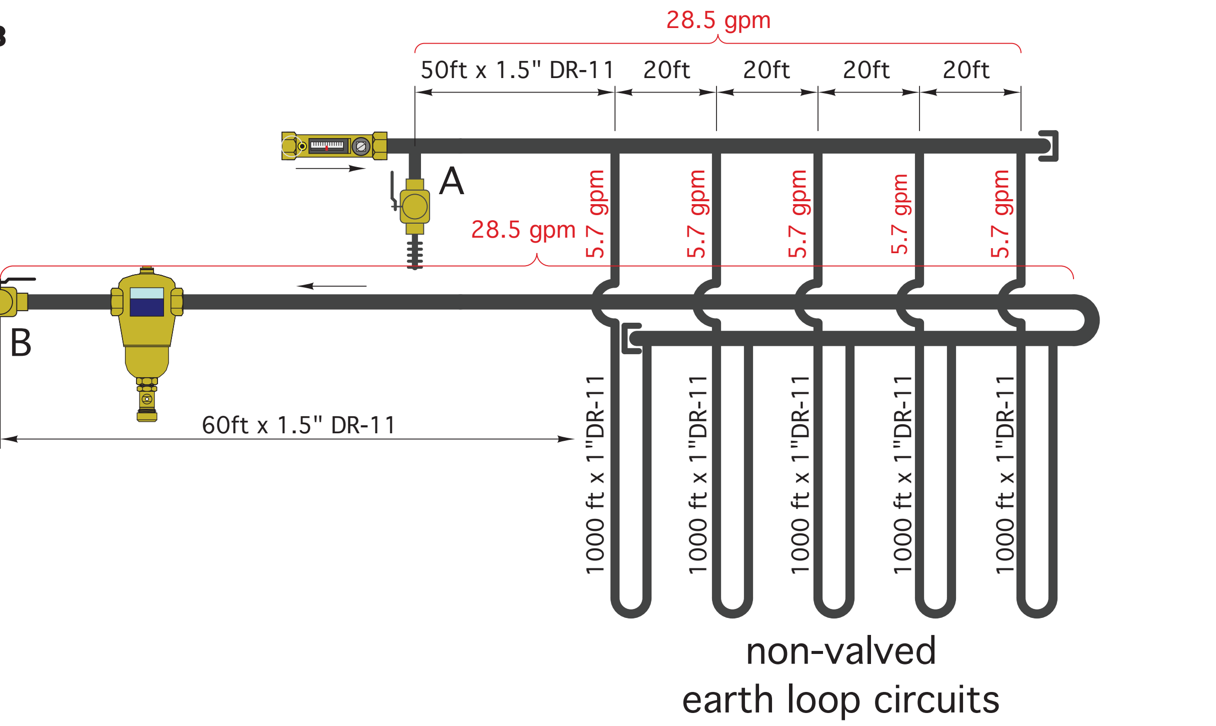
$$H_{L/100'} = R(f)^{1.75} = 0.269(4)^{1.75} = 3.04\, ft / 100'$$

Thus the total head loss of 900 feet of this tubing would be 9 x 3.04 = 27.4 feet.

Example: Estimate the total head loss of the non-valved earth loop shown in Figure 8-3. Assume each parallel circuit is 1-inch DR-11 HDPE tubing operating at its minimum purging flow rate of 5.7 gpm. For simplicity, also assume *all* header piping is operating at the total flow rate of 5 x 5.7 = 28.5 gpm. Disregard the very low head loss of the DIRTCAL dirt separator.

Solution: Since all the earth loop circuits are connected in parallel reverse return, and the header segments between the circuits are relatively short, the flow resistance

Figure 8-3



through each potential flow path between points A and B will be approximately equal. Thus, the total head loss will be the head loss of one circuit of 1000 ft of 1-inch tubing operating at 5.7 gpm, plus the head loss of approximately (4 x 20 + 4 x 20 + 50 + 60) = 270 feet of 1.5-inch DR-11 HDPE tubing operating at 28.5 gpm.

The head loss per 100 feet of the 1-inch circuit will be:

$$H_{L/100'} = R(f)^{1.75} = 0.0939(5.7)^{1.75} = 1.97\,ft/100'$$

The head loss per 100 feet of the 1.5-inch circuit will be:

$$H_{L/100'} = R(f)^{1.75} = 0.0168(28.5)^{1.75} = 5.91\,ft/100'$$

The total head loss will be: 10 x 1.97 + 2.7 x 5.91 = 35.7 feet.

This is a substantial head loss. It implies that proper purging of the non-valved earth loop shown in Figure 8-3 will require a purging pump capable of producing a minimum flow rate of 28.5 gpm at a corresponding head of 35.7 feet. This is well beyond the capability of small wet rotor hydronic circulators or small submersible fluid transfer pumps. This flow/head requirement will instead require a submersible well pump or swimming pool pump. A pump with a minimum 1.5-horsepower motor is often recommended for flushing earth loops serving up to 6-ton systems. Larger non-valved earth loops will require even larger purging pumps.

FILLING AND FLUSHING NON-VALVED EARTH LOOPS

The previous example demonstrates that a powerful purging pump is often necessary to simultaneously purge several parallel (non-valved) earth loop circuits. It is also convenient to have a fluid reservoir from which fluid can be pumped, as well as easily assembled piping for this process.

Figure 8-4

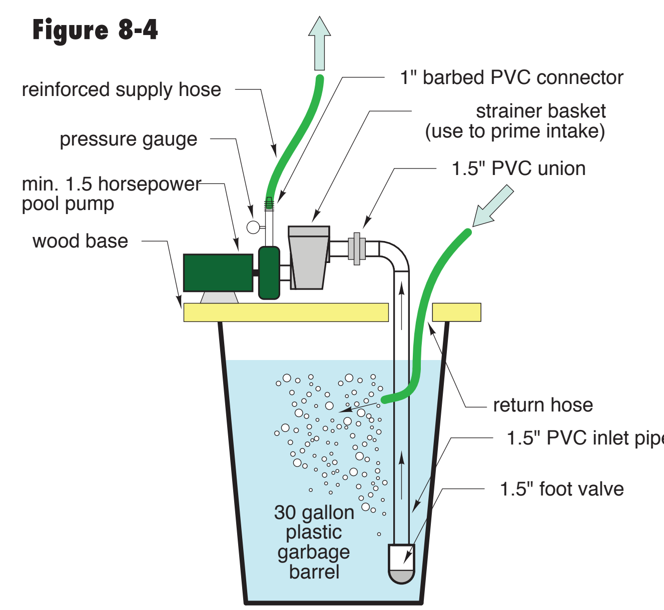
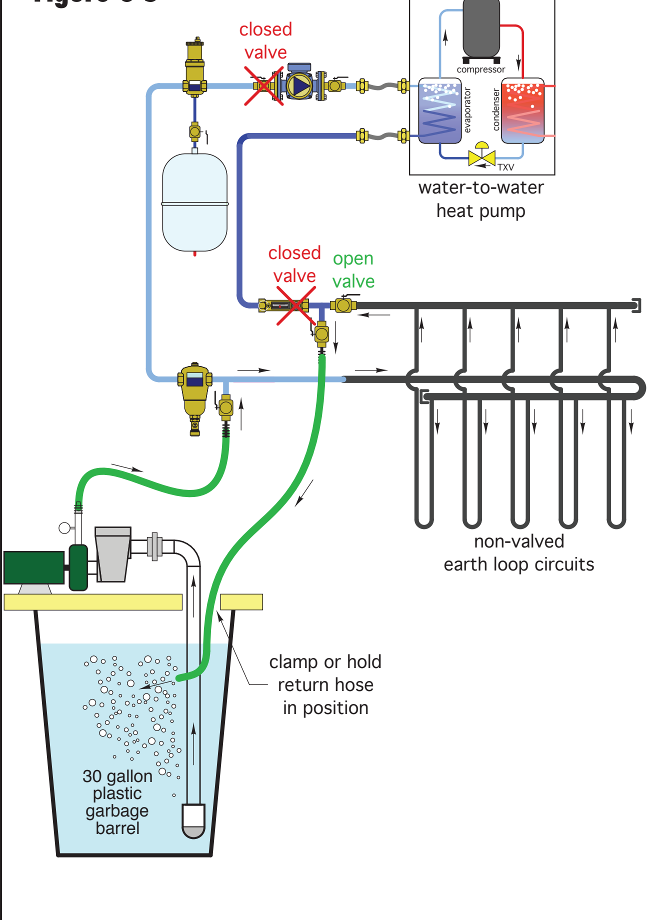


Figure 8-4 shows an example of a “purge barrel” that can be constructed based on a 1.5-horsepower or larger swimming pool pump. The pump is mounted to a wooden base that suspends it over a 30-gallon plastic garbage barrel. Water is drawn into the circulator through a 1.5-inch PVC inlet pipe equipped with a foot valve. The pump volute and inlet pipe are primed by adding water to the strainer basket attached to the pool pump.

Figure 8-5 shows how the purging barrel would be connected to the earth loop being flushed.

Figure 8-5



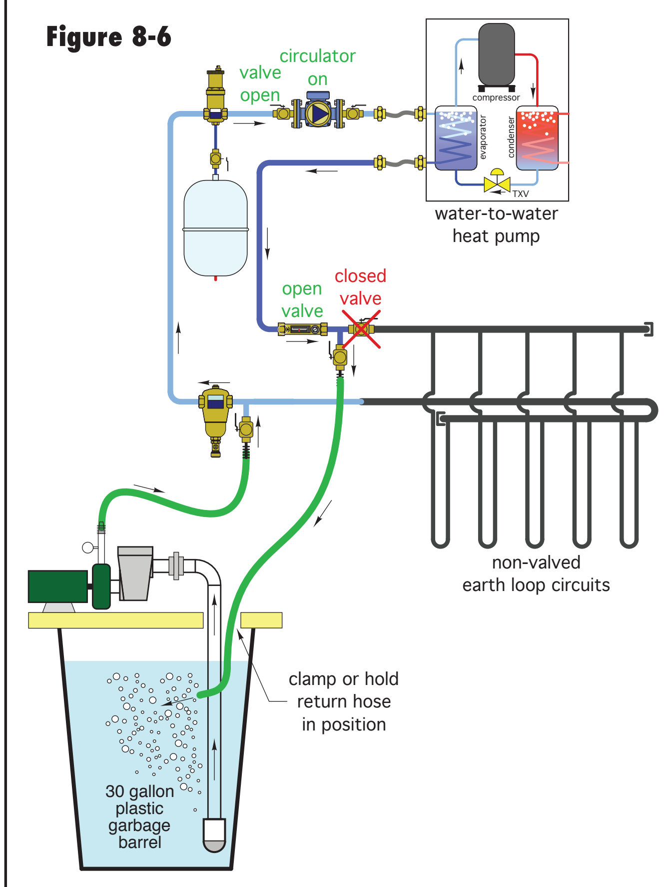
It is very important to use *reinforced* rubber tubing between the purging pump and earth loop valving. This hose will operate under significant pressure during purging. An unreinforced hose could easily burst under this pressure. A hose with a minimum pressure rating of 60 psi is suggested. It is also important to clamp or hold the end of the hose returning to the barrel so that the thrust of the return flow does not lift it out of the barrel. The end of the return hose should be directed so that air bubbles returning to the barrel are not jetted directly toward the foot valve.

The purging process begins by closing the isolation flange of the earth loop circulator as well as the inline valve in the flow-indicating/isolation valve (Caleffi 132). This isolates the circulator and heat pump from the initial purging flow so that any debris in the earth loop in not forced through them. The purging hoses are connected and clamped to the barbed connections at the purging pump and earth loop inlet and outlet valves. Both of these valves are fully opened. The purging pump and inlet line are primed by filling the strainer basket on the pump and then reinstalling the basket’s cover.

The purging pump is now turned on. The water level in the barrel will drop rapidly as water is pumped into the system. It is handy to have several 5-gallon pails of water that can be quickly dumped into the barrel as water is pumped into the system. If the pumping rate exceeds the ability to add water to the barrel, the pump can be temporarily turned off while the barrel is refilled.

As the system fills with water, air will be rapidly forced through the return hose. Soon, this hose will return a mixture of air and water to the barrel. Hold or clamp the return hose so that the returning air bubbles are not aimed directly down to the foot valve location, where they could be re-injected into the system.

Figure 8-6



Eventually the return flow will be mostly free of air bubbles. Allow the purging to continue at least two more minutes to ensure dislodgment of as much air as possible.

When no more bubbles have returned to the barrel for two or more minutes, you are ready to purge the remainder of the earth loop. Open the ball valve in the flow meter/isolation valve (Caleffi 132). Also open the isolation flange on the earth loop circulator. Close the inline ball valve to block purging flow through the earth loop. Flow will now pass through the heat pump and circulator, as shown in Figure 8-6.

More air will be displaced from the piping, heat pump and other components, and return to the purge barrel. This will probably only take a few seconds. Allow the purging flow to continue in this mode for a minute or two to displace all possible air.

Finally, open the ball valve leading to the earth loop while the purging pump continues to operate. This allows simultaneous flow through both the earth loop and interior piping passing through the heat pump. The purging flow rate will rise slightly due to lower overall flow resistance. If the earth loop circulator is wired, it can also be turned on to increase flow and displace air bubbles.

When no further air is returning to the barrel, partially close the outlet purging valve while the purging pump remains on. This will add fluid to the loop, partially compress the air sealed in the expansion tank, and increase the pressure within the loop. A static pressure of 20 to 30 psi is adequate in nearly all earth loops equipped with an expansion tank. When this pressure is achieved, close the *inlet* ball valve between the purging pump and earth loop then turn off the purging pump.

Most newly filled and purged earth loops can be operated for a few days with just water. This provides time for small dirt particles to be removed by the DIRTCAL dirt separator. It also allows time to locate and repair any minor leaks before adding antifreeze to the system.

ADDING ANTIFREEZE TO THE EARTH LOOP

After the system has operated for a few days, the water it contains should be relatively clean. It is now ready for antifreeze. The necessary volume of antifreeze should be calculated based on a reasonably accurate estimate of the total earth loop volume. Figure 8-7 lists the volume for common sizes of DR-11 HDPE pipe.

The volume of other types or sizes of tubing can be determined using Formula 8-3.

Formula 8-3

$$V_{gal/100'} = 4.0852\left(d_i\right)^2$$

Figure 8-7

tubing	volume (gallons / 100 feet)
¾" DR-11 HDPE tubing	3.01 gal/100 ft
1" DR-11 HDPE tubing	4.72 gal/100 ft
1.25" DR-11 HDPE tubing	7.53 gal/100 ft
1.5" DR-11 HDPE tubing	9.86 gal/100 ft
2" DR-11 HDPE tubing	15.41 gal/100 ft

Where:

$V_{gal/100'}$ = volume of piping (gallons/100 ft)
d_i = exact inside diameter of tubing (inch)

The volume of the heat pump's heat exchanger and other small components is usually small compared to the earth loop volume. Still, estimates for these volumes can be made or referenced in manufacturer's literature, and added to the volume of the piping.

Once the total volume of the earth loop has been estimated, the required volume of antifreeze is a simple percentage—typically between 15% and 25%. A 15% (by volume) solution of propylene glycol provides protection against ice crystal formation (e.g., slush) down to a temperature of about 23ºF. A 25% solution will prevent ice crystal formation down to approximately 15ºF.

The purge barrel can also be used to mix and inject antifreeze into a system. The following procedure is suggested:

Step 1: Calculate the amount of antifreeze required using Formula 8-4:

Formula 8-4

$$V_{antifreeze} = (\%)(V_s + V_{b\ min})$$

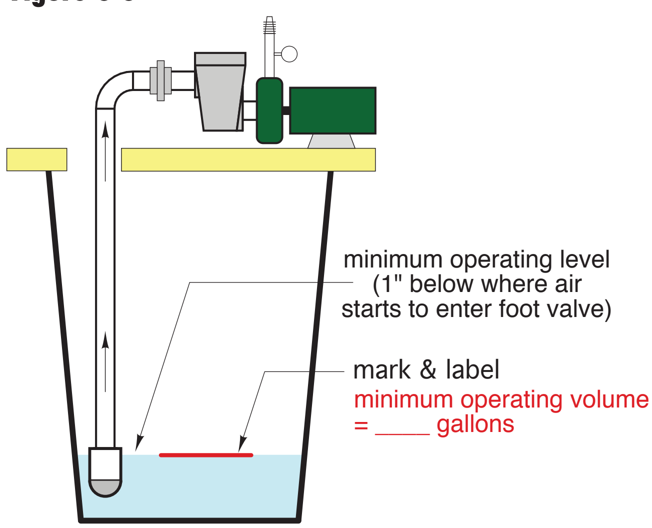
where:

$V_{antifreeze}$ = volume of (100%) antifreeze required (gallons)
% = desired volume % antifreeze required for a given freeze point (decimal %)
V_s = calculated volume of the earth loop (gallons)
$V_{b\ min}$= minimum volume of fluid required in the barrel to allow proper pumping (gallons)*

* The minimum volume of fluid required in the barrel of the purge barrel will depend on how the foot valve is located.

It can be determined by experimenting with the purge barrel (using water). Reduce the water level in the barrel until the pump begins to draw air into the foot valve. Make sure the return hose is located to minimize turbulence around the foot valve. Using a permanent marker, draw a prominent line on the side of the barrel at least 1 inch above this level. This is the minimum operating level of the barrel. Write "Minimum Operating Level" on the outside of the barrel just above this line. Fill the barrel to this line, then carefully pour it out into containers of known volume. Once the total volume is measured, write it on the side of the barrel as shown in Figure 8-8.

Figure 8-8



Step 2: Drain an amount of water from the earth loop equal to the required volume of antifreeze calculated in step 1. This water can either be drained from a low point valve or, if necessary, forced from the earth loop by adding compressed air through another valve.

Step 3: Attach the purging hoses to the system as shown in Figure 8-5. Keep both inlet and outlet valves closed.

Step 4: Fill the barrel to its minimum operating level with water, then pour in the required volume of antifreeze calculated in step 1. Turn on the purging pump. Open the inlet and outlet valves to the system. If the barrel will not hold this volume, the antifreeze can be poured into the barrel as the flow level drops once filling is underway.

Step 5: Follow the same purging procedures described earlier. Allow the mixture to circulate through the system for a few minutes to thoroughly mix the water and antifreeze.

Step 6: When no visible air is returning to the barrel, partially close the outlet valve to pressurize the system. For an earth loop (without an expansion tank) that is being purged in the summer, the suggested static pressure is 20 to 30 psi. If that earth loop is being purged in the winter, the suggested static pressure is 40 to 50 psi. The higher static pressure during winter, when the earth loop and fluid is cold, prevents excessive pressure drop in the loop when it warms during cooling operation. Earth loops equipped with properly sized expansion tanks, as described in section 9, can operate with lower static pressures, typically in the range of 20 psi. Once the appropriate static pressure is reached, close the inlet valve. If the system pressure is higher than desired, drain some of the fluid back into the barrel through the return hose. If the pressure is lower than needed, add fluid to the system with a hand pump.

Step 7: The system should now contain the desired concentration of antifreeze and be purged of all but dissolved air. Turn off the purge cart and disconnect the hoses. The fluid remaining in the purge barrel will have the same concentration of antifreeze as the fluid in the earth loop. It can be poured into clean containers and saved for use in future systems. Be sure to label the storage containers with a description of the fluid, as well as the date it was stored.

FILLING AND PURGING VALVED EARTH LOOPS

One distinct advantage of a valved earth loop is the ability to purge each earth loop circuit one at a time. This significantly reduces the capacity of the purging pump relative to non-valved systems.

The suggested piping and purging connections for a valved manifold earth loop system are shown in Figure 8-9.

As with non-valved earth loops, it is preferable to purge the buried portion of the earth loop before purging the interior piping passing through the heat pump and loop circulator. This recognizes that the higher probability for dirt is within the buried piping.

It is still necessary to select a purging pump with sufficient flow and head capacity to purge each earth loop circuit individually. For example, if each earth loop circuit was a 1000-foot-long loop of 1-inch DR-11 HDPE pipe, the minimum purging flow rate would be 5.7 gpm (see Figure 8-1), and the required head would be 10 times the head loss per 100 feet.

The head loss per 100 feet of 1-inch DR-11 HDPE pipe is found using Formula 8-2:

Formula 8-2

$$H_{L/100} = R(f)^{1.75} = 0.0939(5.7)^{1.75} = 1.97\,ft/100'$$

Figure 8-9

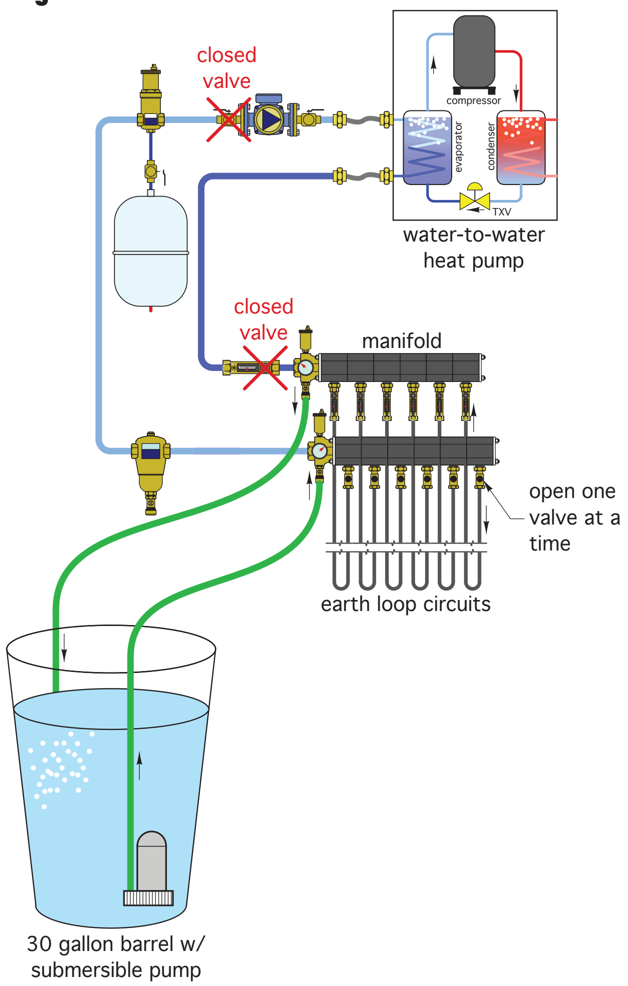
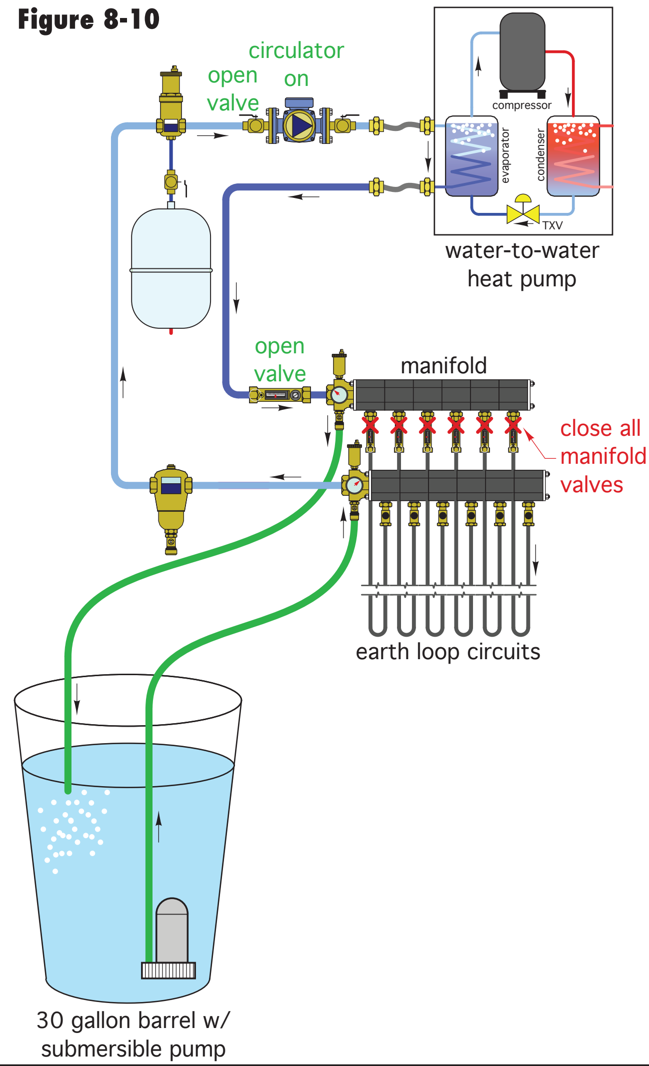


Figure 8-10



Thus, the total head loss of 1000 feet of this pipe is 10 x 1.97 = 19.7 feet.

A nominal 5% should be added to the head loss to account for the flow resistance created by the manifold components and purging hoses. Thus, the minimum purging pump requirement for the earth loop would be a flow rate of 5.7 gpm with corresponding head loss of (1.05)19.7 = 20.7 feet.

The capacity of the purging pump should also be checked against the minimum flow rate required to purge the interior portion of the earth loop. The purging pump should be able to create a flow velocity of at least 2 feet per second within the largest pipe size used in the loop.

The purging procedure is the same as would be used for a manifolded hydronic distribution system, such as used for radiant panel heating.

Step 1: Connect the purging hoses as shown in Figure 8-9.

Step 2: Fill the purging barrel with water

Step 3: Open the circuit valve at one end of the manifold and close all other circuit valves.

Step 4: Open the purging inlet and outlet valves on the manifold.

Step 5: Close the inline ball valve in the flowmeter/isolation valve (Caleffi 132), as well as the valve on the loop circulator inlet flange.

Step 6: Hold or fasten the return hose near the top of the barrel.

Step 7: Turn on the purging pump. Water will flow into the supply manifold and push air through the one open earth loop circuit. The air will return to the barrel. Eventually, the return stream will transition from air to water. When the return stream appears to be running free of visible air, open the isolation valve for the adjacent circuit on the manifold, then close the isolation valve for the circuit just purged. Repeat this procedure for each circuit until every circuit on the manifold has been purged. Add water to the purging barrel as necessary during this process.

Step 8: Once the buried portion of the earth loop has been purged, open the flow meter/isolation valve (Caleffi 132), as well as the isolation valve on the circulator inlet flange. Close all earth loop valves. The purging flow is now directed through the heat pump's heat exchanger, circulator and other interior portions of the earth loop. Continue purging this portion of the system until the return stream is free of air bubbles. If the circulator is wired, it can be turned on to further increase purging flow and dislodge air bubbles. This purging mode is shown in Figure 8-10.

Figure 8-11

Step 9: Open all the earth loop circuit valves on the manifold to allow simultaneous purging of all portions of the earth loop. When no further air is returning to the barrel, close the outlet purging valve while the purging pump is still operating. This will add water to the loop, partially compress the air sealed in the expansion tank and increase the loop's static pressure. A static pressure between 15 and 40 psi is fine for initial operation of the loop, before adding antifreeze.

Step 10: Most newly filled earth loops should be operated for a few days with just water in the earth loop. This provides time for small dirt particles to be removed by flowing through the dirt separator.

Step 11: Follow the previously described procedure for adding antifreeze to the earth loop. Once the antifreeze has been added and the loop purged, the static pressure of the loop can be adjusted. If an earth loop (without an expansion tank) is being purged in the summer, the suggested static pressure is 20 to 30 psi. If an earth loop (without an expansion tank) is being purged in the winter, the suggested static pressure is 40 to 50 psi. The higher static pressure during winter, when the earth loop and fluid is cold, prevents excessive pressure drop in the loop when it warms during cooling operation. If the purging pump is not capable of reaching these pressures, a small hand pump such as shown in Figure 8-11 can be used to increase system pressure.

For earth loops equipped with properly sized expansion tanks, as described in section 9, the static pressures can be reduced. A nominal 20 psi static pressure during commissioning is generally adequate.

9. EXPANSION TANKS FOR EARTH LOOPS

There are varied opinions regarding the use of expansion tanks within closed geothermal earth loops. Some suggest that the tank is not needed based on the ability of the HDPE tubing to absorb some of the volumetric expansion of the earth loop fluid with "acceptable" variations in earth loop pressure. Hundreds, perhaps thousands, of earth loops have been installed without expansion tanks, primarily in North America. Some have operated acceptably, while others have experienced pressure variations that have caused problems.

Most European geothermal heat pump installations *do* include an expansion tank as a standard part of the earth loop. The reasoning is that such a tank reduces pressure fluctuations and averts some of the problems associated with "tankless loops."

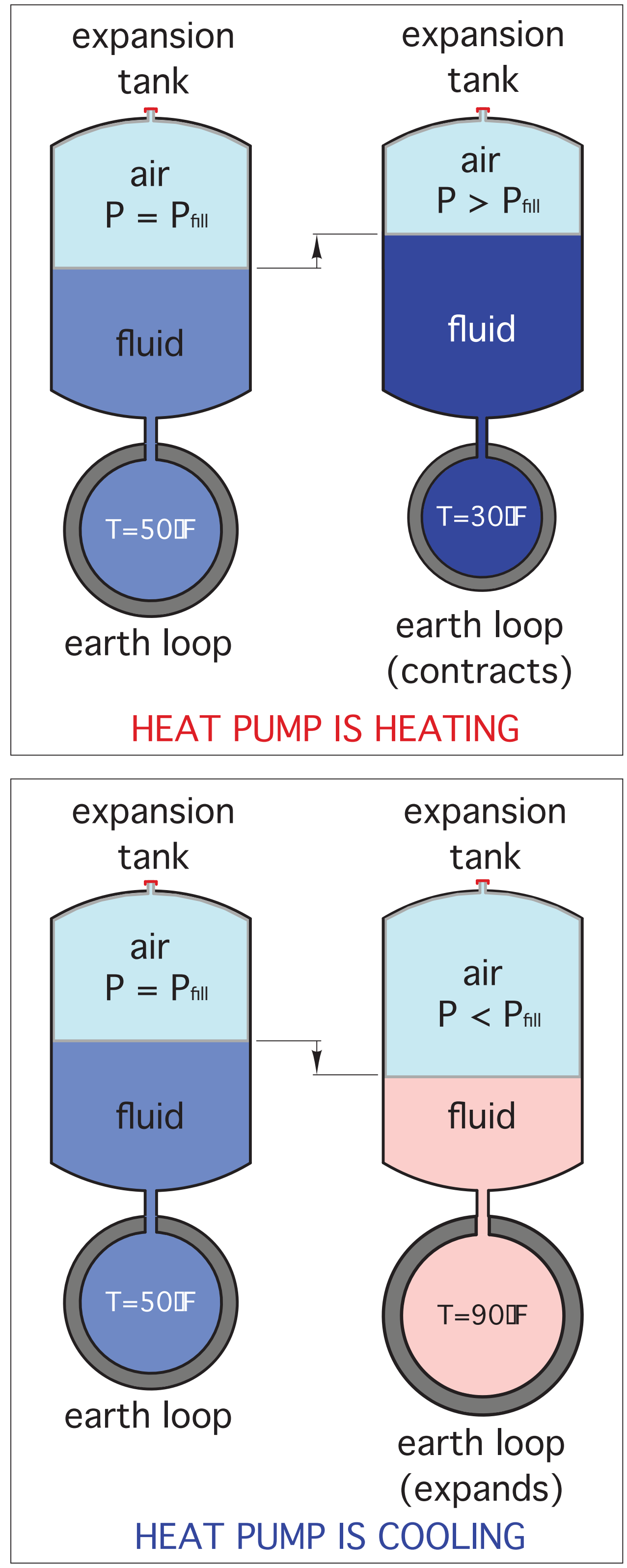
One characteristic of earth loops is that the fluid within them expands and contracts at a different rate than the volumetric expansion and contraction of the HDPE piping. *As the earth loop fluid and piping cool, the internal volume of the loop piping decreases at a greater rate than the volumetric contraction of the fluid within the piping.* This causes a pronounced increase in loop pressure in systems not equipped with expansion tanks. This pressure rise increases the potential for fluid leaks at piping connections.

When the heat pump is operating in cooling mode, the temperature of the earth loop fluid and piping increase. *Under such conditions, the internal volume of the piping increases at a greater rate than the volumetric expansion of the fluid.* This causes a drop in earth loop pressure. In systems without an expansion tank, the fluid pressure at the inlet of the earth loop circulator may drop low enough to cause circulator cavitation. Under such conditions, the earth loop is said to be "flat." A cavitating circulator will not produce proper flow rates, creates unacceptable noise levels and may eventually fail due to erosion of the impeller or volute. Installing an expansion tank in the earth loop is one way to avoid such problems.

DETERMINING NET VOLUME CHANGES IN THE EARTH LOOP

Figure 9-1 illustrates fluid being pushed into the expansion tank from the contracting earth loop when the heat pump is operating in heating mode (e.g., earth loop temperature is decreasing). It also illustrates fluid flowing out of the expansion tank into an expanding earth loop when the heat pump is operating in the cooling mode (e.g., earth loop temperature is increasing). The minimum and maximum earth loop temperatures indicated are typical.

Figure 9-1



Formula 9-1 can be used to determine the volume of fluid *drawn out* of the expansion tank when the earth loop temperature is increasing:

Formula 9-1

$$V_{out} = V_{loop}\left[\left(\alpha(\Delta T)+1\right)^3 - \left(\frac{D_{fill}}{D_{high}}\right)\right]$$

Where:

V_{out} = volume of fluid flowing out of expansion tank (gallons)
V_{loop} = total volume of earth loop when filled and purged (gallons)
α = coefficient of linear expansion of earth loop piping (in/in/ºF)
ΔT = absolute value (e.g., always a positive number) of temperature change of loop (ºF)
D_{fill} = density of fluid when loop is filled and purged (lb/ft^3)
D_{high} = density of fluid when loop is at *maximum* temperature (lb/ft^3)

Formula 9-2 can be used to determine the volume of fluid *added* to the expansion tank when the earth loop temperature is decreasing:

Formula 9-2

$$V_{in} = V_{loop}\left[\left(\frac{D_{fill}}{D_{low}}\right) - \left(1-\alpha(\Delta T)\right)^3\right]$$

Where:

V_{in} = volume of fluid flowing *into* of expansion tank (gallons)
V_{loop} = total volume of earth loop when filled and purged (gallons)
α = coefficient of linear expansion of earth loop piping (in/in/ºF)
ΔT = absolute value (e.g., always a positive number) of temperature change of loop (ºF)
D_{fill} = density of fluid when loop is filled and purged (lb/ft^3)
D_{low} = density of fluid when loop is at *minimum* temperature (lb/ft^3)

Example: An earth loop contains the following tubing:

5000 feet of 1-inch DR-11 HDPE tubing
200 feet of 1.5-inch DR-11 HDPE tubing

The earth loop operates with a 20% solution of propylene glycol antifreeze. The system is filled with this solution when the earth loop piping and fluid are both at 50ºF. Determine the amount of fluid:

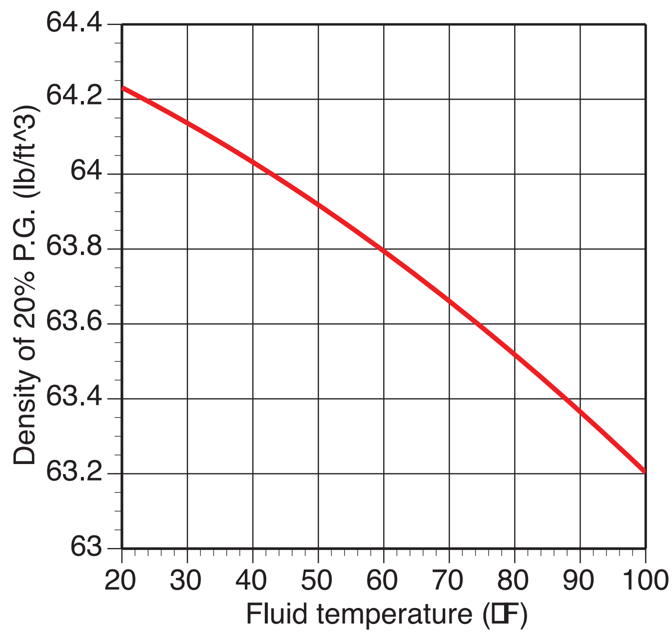
A) Extracted from the expansion tank when the loop temperature increases to 90ºF.

B) Added to the expansion tank when the loop temperature drops to 30ºF.

Solution: The total volume of the earth loop is found using data from Figure 8-7:

$$5000\,ft\left(\frac{4.72\,gal}{100\,ft}\right) + 200\,ft\left(\frac{9.86\,gal}{100\,ft}\right) = 256\,gallons$$

Figure 9-2



The density of the 20% propylene glycol fluid is found at the required temperatures based on manufacturer's specifications. It can also be found in Figure 9-2.

For 20% propylene glycol at 90ºF: D = 63.37 lb/ft^3
For 20% propylene glycol at 50ºF: D = 63.92 lb/ft^3
For 20% propylene glycol at 30ºF: D = 64.14 lb/ft^3

The coefficient of linear expansion for HDPE tubing is 0.0001 in/in/ºF.

The amount of fluid removed from the expansion tank when the loop is raised from 50ºF to 90ºF would be:

$$V_{out} = V_{loop}\left[\left(\alpha(\Delta T)+1\right)^3 - \left(\frac{D_{fill}}{D_{high}}\right)\right] = 256\left[\left(0.0001(40)+1\right)^3 - \left(\frac{63.92}{63.37}\right)\right] = 0.86\,gallon$$

The amount of fluid added to the expansion tank when the loop is lowered from 50ºF to 30ºF would be:

$$V_{in} = V_{loop}\left[\left(\frac{D_{fill}}{D_{low}}\right) - \left(1-\alpha(\Delta T)\right)^3\right] = 256\left[\left(\frac{63.92}{64.14}\right) - \left(1-0.0001(20)\right)^3\right] = 0.66\,gallons$$

Keep in mind that these are the *net* volume changes that result from the combination of expansion/contraction of the fluid as well as that of the earth loop tubing.

SELECTING AN EXPANSION TANK

An expansion tank can now be selected that accommodates these volumes with an acceptable change in pressure.

Example: Determine the expansion tank volume required to accommodate the fluid extraction of 0.86 gallons in the previous example, while dropping from an initial air side pressure of 20 psi to 10 psi. Assume the tank is initially half-filled with fluid as the loop begins heating up.

Solution: Boyle's law is set up and solved based on these assumptions:

$$V_{tank} = \frac{2(V_{out})}{\left(\frac{P_i + 14.7}{P_f + 14.7}\right) - 1}$$

Where:

V_{tank} = required volume of expansion tank (gallons)
V_{out} = volume of fluid leaving tank as loop heats to max operating temperature (from Formula 9-1) (gallons)
P_i = initial air side pressure in tank (when loop is charged) (psig)
P_f = final air side pressure in tank (when loop is at max. temperature) (psig)

$$V_{tank} = \frac{2(V_{out})}{\left(\frac{P_i + 14.7}{P_f + 14.7}\right) - 1} = \frac{2(0.86)}{\left(\frac{20 + 14.7}{10 + 14.7}\right) - 1} = 4.25\,gallons$$

Thus, an expansion tank of 4.25 gallons total shell volume initially at 20 psi air side pressure and half-filled with fluid will allow the system loop pressure to drop from 20 to 10 psi. This is a reasonable change in pressure that should not adversely affect the operation of a properly installed circulator (e.g., circulator positioned so that it pumps away from the expansion tank location). Selecting an expansion tank slightly larger than the calculated 4.25 gallons will further reduce the pressure change in the earth loop.

Note: When setting up this tank, the air side pressure should be adjusted to approximately 10 psig. When the loop is charged to 20 psi, the air volume in the tank will be compressed to half its original volume and thus be at 20 psi. The tank will be half-filled with fluid under this condition.

The extra fluid volume in the expansion tank is desirable in systems with air separators. It provides some "makeup" fluid that eventually fills the void left by air being separated and ejected from the system.

Example: Assume that the designer selected a 6 gallon expansion tank for this example system. The tank has an initial air charge of 10 psi, but is half filled with fluid when the loop is initially charged to 20 psi. Determine the maximum pressure it will reach when the earth loop drops to its lowest temperature of 30 ºF.

Solution: Again, Boyle's law yields the following:

$$P_f = \frac{(P_i + 14.7)}{\left(1 - \frac{2V_{in}}{V_{tank}}\right)} - 14.7$$

Where:

P_f = final air side pressure in tank (when loop is at max. temperature) (psig)
P_i = initial air side pressure in tank (when loop is charged) (psig)
V_{tank} = selected volume of expansion tank (gallons)
V_{in} = volume of fluid entering tank as loop drops to min. operating temperature (gallons)

$$P_f = \frac{(P_i + 14.7)}{\left(1 - \frac{2V_{in}}{V_{tank}}\right)} - 14.7 = \frac{(20 + 14.7)}{\left(1 - \frac{2(0.66)}{6}\right)} - 14.7 = 29.8\,psi$$

The pressure rise from 20 to almost 30 psi is fine. It will not cause any operational problems.

If the designer had instead elected to use a 4.25-gallon expansion tank, the loop pressure at minimum operating temperature would be about 35.6 psi—still very acceptable.

In systems where the earth loop is warmed during the cooling season and cooled during the heating season, the net volume change of the expansion tank should be evaluated in both modes. The expansion tank can then be sized based on the more constraining condition. Typically, this will be the acceptable drop in loop pressure during loop warming (cooling mode of the heat pump).

To summarize: A typical earth loop sized for a 5-ton geothermal heat pump system is calculated to contain 256 gallons of a 20% propylene glycol fluid. The expansion tank has an initial air side pressure of 10 psi, and the system is charged to a static pressure of 20 psi (half filling the expansion tank with fluid). When the earth loop reaches its maximum operating temperature of 90ºF, the loop pressure drop was limited to 10 psi. This would require an expansion tank volume of 4.25 gallons. The designer opted to use a 6-gallon expansion tank. With this tank, and when the loop reaches its minimum operating temperature of 30ºF, its static pressure increases to 29.8 psi.

Designers can use the equations presented in the section to experiment with different pressure variations, fluid properties and loop volumes to see the effect on expansion tank sizing.

SUMMARY

Heat pumps are unique in their ability to provide both heating and cooling from a single machine. The combination of heat pumps with modern hydronics technology offers tremendous flexibility for HVAC designers to create unique heating and cooling systems. Such systems leverage the high distribution efficiency and accurate control of hydronics to enhance the thermal efficiency of heat pumps. Such systems can be used in both residential and commercial facilities. They are also ideal in situations where designers aspire to create “net zero” buildings.

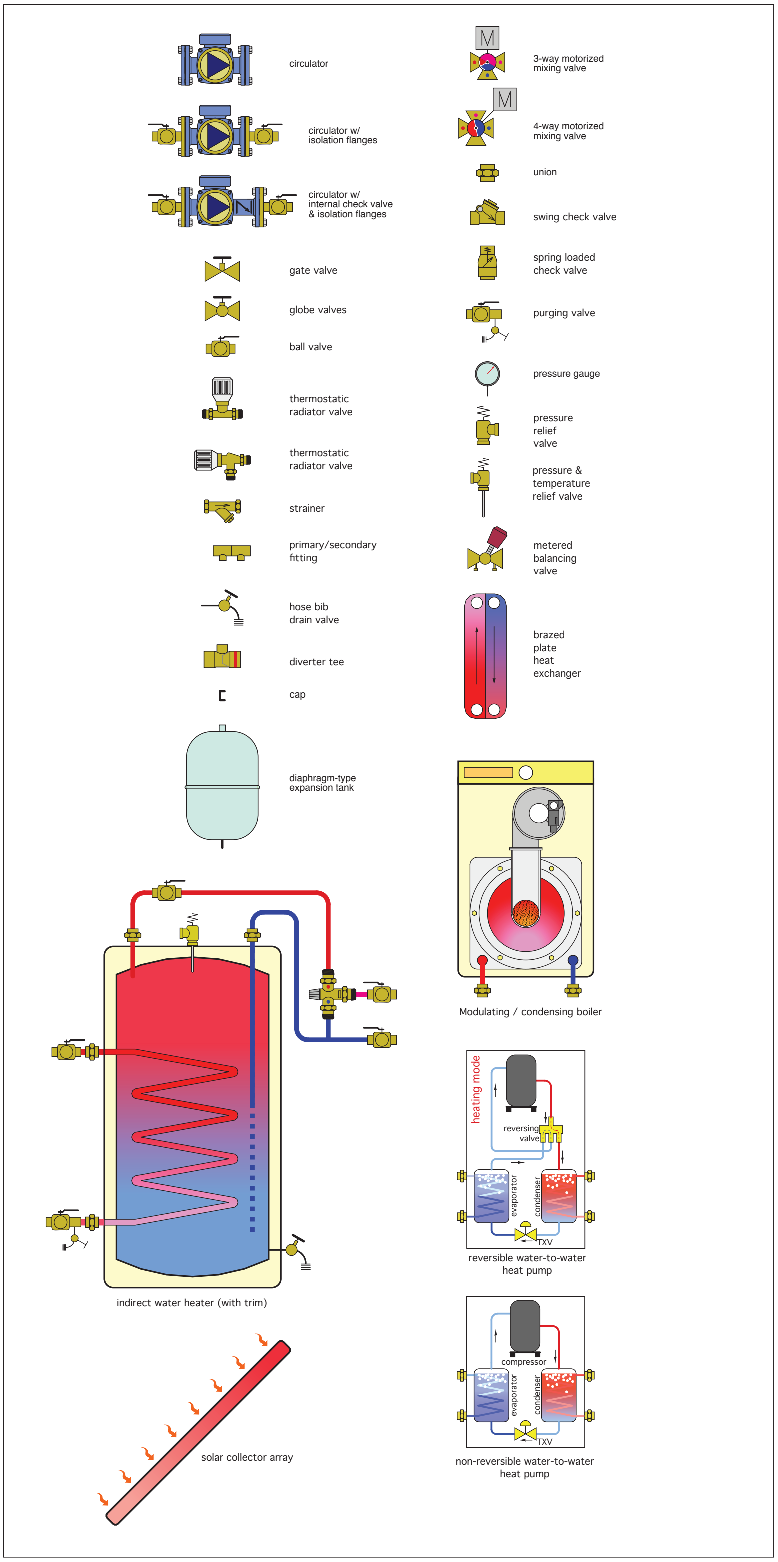
The availability of air-to-water heat pumps allows designers to achieve these benefits in situations where space is not available for geothermal earth loops.

Incorporating thermal storage into systems creates additional possibilities for leveraging time-of-use electrical rates, or merging other heat sources such as solar collectors or solid fuel boilers into the system. Control methods can be optimized to use these sources in ways that minimize total operating cost. A properly configured hydronic distribution system uses these energy flows to create superior and uninterrupted comfort within the building.

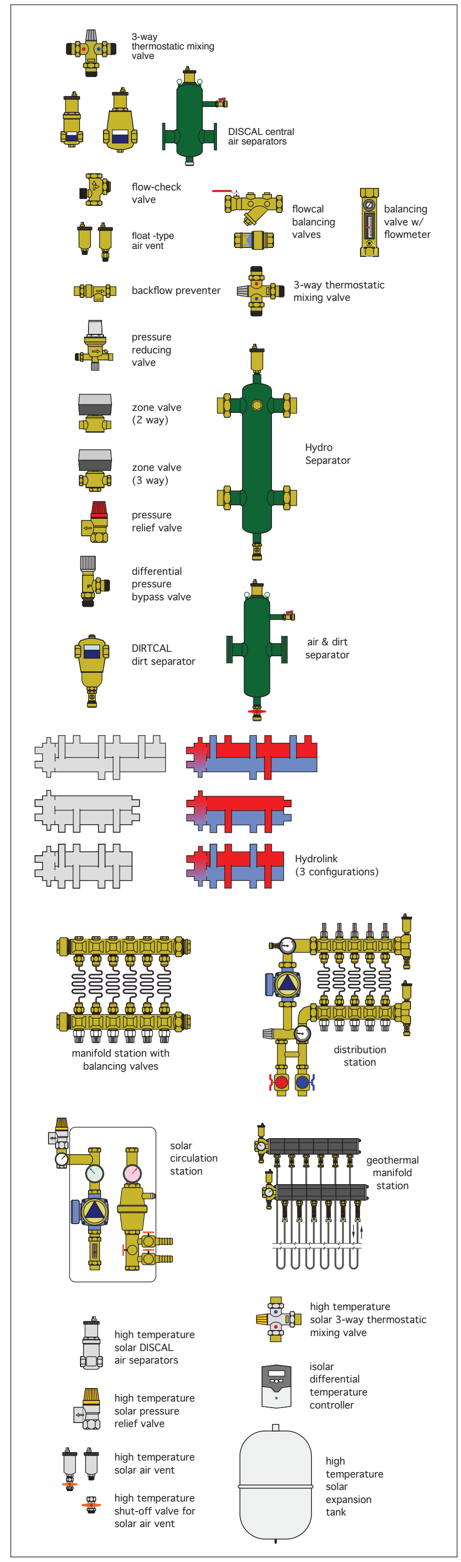
The future of hydronic-based heat pumps is indeed promising.

Appendix A: Schematic Symbols

GENERIC COMPONENTS



CALEFFI COMPONENTS



Appendix B: Earth Loop Estimates

The calculations required to determine the earth loop length required for a given geothermal heat pump system are beyond the scope of this journal. The necessary procedures and data are given in the reference cited below. There are also several software packages available for evaluation of earth loop requirements.

Figure B-1 can be used for "rough estimates" of earth loops. It is based on several assumptions for depth, soil properties, tube size and tube spacing. *Figure B-1 should NOT be used for final designs, but only for conceptualizing the approximate land area and pipe quantities during initial planning.*

Figure B-1

Slinky loop	125 to 150 feet of trench per ton of heat pump output
4-pipe square loop	160 to 250 feet of trench per ton of heat pump capacity
single vertical U-tube	150–225 feet of bore hole per ton of heat pump capacity

Factors that tend to DECREASE the required earth loop size (based on heating mode):

- higher average soil temperature
- wetter soils
- higher-density soils
- deeper placement of tubing
- wider tube spacing
- larger diameter tubing

Factors that tend to INCREASE the required earth loop size (based on heating mode):

- lower average soil temperature
- dry soils
- low-density soils
- tubing placed closer to earth surface
- closer tube spacing
- small diameter tubing

Reference:
Ground Source Heat Pump Residential and Light Commercial Design and Installation Guide
by International Ground Source Heat Pump Association
© 2009
ISBN 978-0-929974-07-1

Appendix C: Buffer Tank Sizing Calculation

The size of the buffer tank used in a system is determined by the desired "on-time" of the heat pump and the acceptable temperature rise of the water in the buffer tank during this on-time. The on-time is that time between when the heat pump turns on to begin warming the tank and when it turns off after lifting the tank temperature through the acceptable temperature rise. Formula C-1 can be used to determine tank size.

Formula C-1

$$V_{btank} = \frac{t(Q_{HP} - Q_L)}{500(\Delta T)}$$

Where:

V_{btank} = required volume of buffer tank (gallons)
t = desired on-time for heat source (minutes)
Q_{HP} = heating capacity of heat pump (Btu/hr)
Q_L = any heating load that is active when the buffer tank is charging (Btu/hr)
ΔT = allowed temperature rise of tank during heat pump on-time (ºF)

Example: Determine the size of a buffer tank that will absorb 48,000 Btu/hr while increasing in temperature from 90ºF to 110ºF during a heat pump on-cycle of 10 minutes. Assume there is no active heating load during this charging.

Solution: The temperature rise (ΔT) is 110 - 90 = 20ºF. Putting this and the remaining data into Formula C-1 yields:

$$V_{btank} = \frac{t(Q_{HP} - Q_L)}{500(\Delta T)} = \frac{10(48000-0)}{500(20)} = 48\,gallons$$

If the allowed temperature rise was 10ºF rather than 20ºF, the required tank volume would double to 96 gallons. If the desired on-time was only 5 minutes rather than 10 minutes, the volume would be cut in half. Anything that increases the desired on-time or decreases the allowed temperature rise during this on-time will increase the required tank volume, and vice versa.

The same formula can be used to determine the size of a buffer tank used for cooling. The value of Q_{HP} would be the cooling capacity of the heat pump. The value of ΔT would be the allowed temperature drop in the tank during this on-time.

Appendix D: Design Information On Earth Loop Head Loss

The head loss of DR-11 HDPE tubing often used for earth loops can be determined using Formula D-1, the data in Figure D-1 and the correction factors for antifreeze solutions in Figure D-2a, D-2b, and D-2c:

Formula D-1

$$H_{L/100'} = cR(f)^{1.75}$$

Where:
$H_{L/100'}$ = head loss of piping operating with 40ºF water (ft of head per 100 ft of tubing)
c = correction factor for various antifreeze solutions and fluid temperatures (from table D-2a,b,c)
R = number for given size of DR-11 HDPE tubing (from Figure D-1)
f = flow rate (gpm)

Figure D-1

tubing	R (water @ 40°F)
¾" DR-11 HDPE tubing	R = 0.269
1" DR-11 HDPE tubing	R = 0.0939
1.25" DR-11 HDPE tubing	R = 0.0316
1.5" DR-11 HDPE tubing	R = 0.0168
2" DR-11 HDPE tubing	R = 0.0059

Figure D-2a

PROPYLENE GLYCOL	40°F	30°F	20°F
15% propylene glycol	c = 1.19	c = 1.25	*
20% propylene glycol	c = 1.24	c = 1.31	c = 1.39
25% propylene glycol	c = 1.34	c = 1.42	c = 1.52

* insufficient freeze protection

Figure D-2b

METHANOL	40°F	30°F	20°F
10% methanol	c = 1.13	c = 1.18	*
15% methanol	c = 1.17	c = 1.23	c = 1.31
20% methanol	c = 1.20	c = 1.26	c = 1.35

* insufficient freeze protection

Figure D-2c

ETHANOL	40°F	30°F	20°F
15% ethanol	c = 1.26	c = 1.36	*
20% ethanol	c = 1.31	c = 1.42	c = 1.56
25% ethanol	c = 1.35	c = 1.47	c = 1.64

* insufficient freeze protection

Example: Determine the head loss of 900 feet of ¾" DR-11 HDPE tubing operating at with a 20% solution of propylene glycol at 30ºF and a flow rate of 4 gpm.

Solution: The head loss of the tubing per 100 feet of length is found using Formula D-1 along with the value of R = 0.269 and the antifreeze correction factor c = 1.31:

$$H_{L/100'} = cR(f)^{1.75} = (1.31)(0.269)(4)^{1.75} = 3.99\, ft/100'$$

Thus, the total head loss of 900 feet of this tubing would be 9 x 3.99 = 36 feet.

Cooler fluids and higher concentrations of antifreeze will increase the head loss within a given piping circuit. The limiting condition is thus achieving the required earth loop flow rate at the lowest expected fluid temperature, and at the corresponding head loss.

Appendix E: Estimating Heat Pump Performance

It is possible to *estimate* the current heating capacity and COP of a water-source heat pump based on measurements of the source fluid flow rate and temperature differential across the earth connections to the heat pump. Placement of a Caleffi 132 isolation/flow setter valve, as shown in Figure E-1, enables the flow rate measurement. Instrument(s) capable of simultaneously reading the temperature at the inlet and outlet piping connections to the heat pump (or the difference between these temperatures) are also required. To maintain accuracy, both temperature sensors should be securely strapped to metal piping and then wrapped with insulation. Alternatively, each temperature sensor could be mounted in a sensor well.

The rate of heat supplied by the earth loop at any given time can be calculated using Formula E-1.

Formula E-1

$$Q_{eloop} = k \times f \times (T_{in} - T_{out})$$

Where:

Q_{eloop} = rate of heat transfer into heat pump from earth loop (Btu/hr)
f = earth loop flow rate (gpm)
T_{in} = temperature of earth loop fluid entering heat pump evaporator (°F)
T_{out} = temperature of earth loop fluid leaving heat pump evaporator (°F)
k = a number depending on the earth loop fluid
for water k = 500 for 20% propylene glycol (at average temperature of 45°F) k = 483

For other fluids, calculate the value of k using Formula E-2.

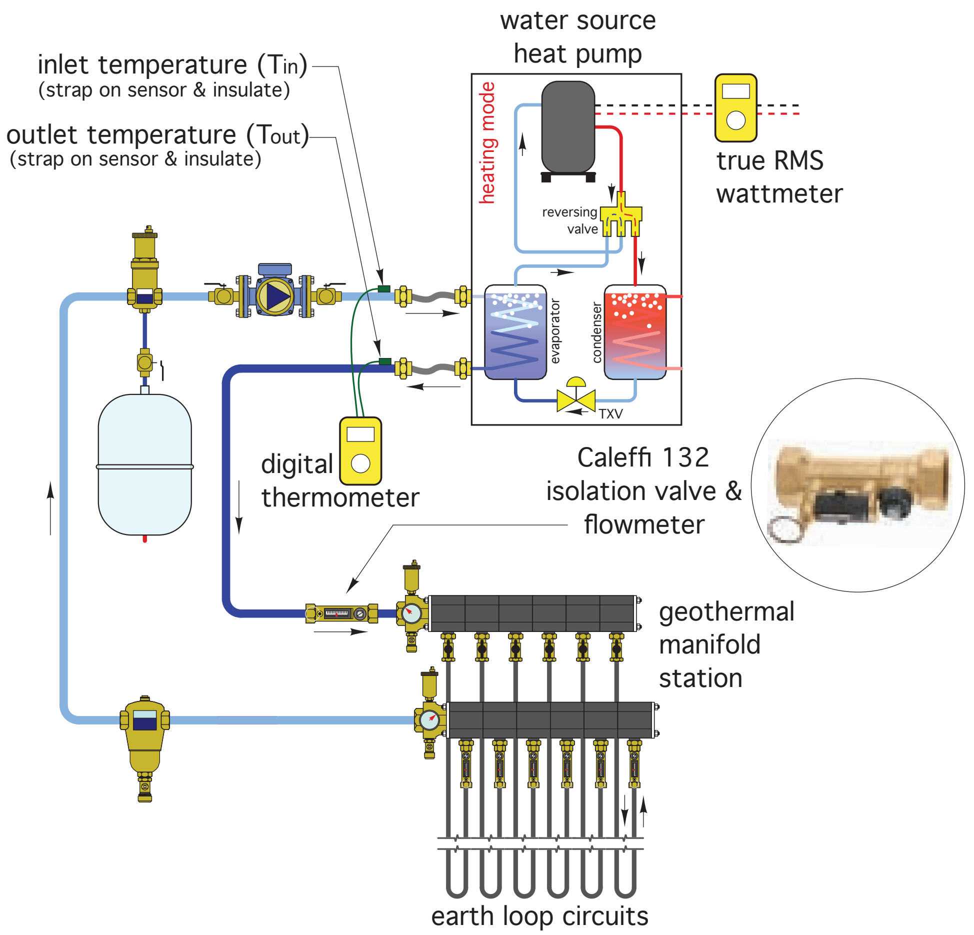
Formula E-2

$$k = 8.01 \times c \times D$$

Where:

c = specific heat of earth loop fluid at its current average temperature (Btu/lb/°F)
D = density of earth loop fluid at its current average temperature (lb/ft^3)

Figure E-1



It is also necessary to measure the true RMS electrical wattage supplied to operate the heat pump. Digital meters that tap into the power supply wiring to the heat pump can be used for this. Due to variations in power factor, measuring the current and voltage supplied to the heat pump and then multiplying these by an assumed power factor is *not* sufficiently accurate for estimating true power input to the heat pump.

Ideally, the temperature difference across the heat pump's evaporator, the earth loop flow rate and the power input to the heat pump should all be measured at the same instant. Since this is not always possible, it is best to wait until these parameters are all relatively stable and then record them in the shortest possible time.

Once the measurements are taken, the instantaneous rate of heat output (Q_{out}) from the heat pump can be calculated by adding the heat input from the earth loop (Q_{eloop}) to the electrical power input to the compressor (w) using Formula E3.

Formula E-3

$$Q_{out} = Q_{eloop} + w \times (3.413)$$

Where:
Q_{out} = instantaneous rate of heat output from the heat pump (Btu/hr)
Q_{eloop} = instantaneous rate of heat input from earth loop (Btu/hr)
w = instantaneous true RMS power input to heat pump (watts)

The instantaneous COP (Coefficient Of Performance) of the heat pump can be calculated using Formula E-4.

Formula E-4

$$COP = \frac{Q_{out}}{w \times (3.413)}$$

If the heat pump is operating in the *cooling* mode, its instantaneous *cooling* capacity (Q_{cool}) and EER (Energy Efficiency Ratio) can be calculated from these measurements and calculations using Formulas E-5 and E-6.

Formula E-5

$$Q_{cool} = \left[8.01 \times c \times D \times f \times (T_{out} - T_{in})\right] - w \times (3.413)$$

Where:
Q_{cool} = instantaneous cooling capacity (Btu/hr)

Formula E-6

$$EER = \frac{Q_{cool}}{w}$$

Example: The data acquired for a water-source heat pump operating in heat mode is as follows: T_{in}= 51.1ºF, T_{out} = 40.3ºF, f = 7.0 gpm, w = 3500 watts. The earth loop is operating with a 20% solution of propylene glycol. Determine the instantaneous heating capacity (Qout) and COP of the heat pump.

Solution:

$$Q_{eloop} = k \times f \times (T_{in} - T_{out}) = 483 \times 7.0 \times (51.1 - 40.3) = 36{,}515\,Btu/hr$$

Glycol correction factor: Due to differences in density and viscosity of glycol-based antifreeze solutions, the indicated flow rates on the 132 flow setter should be multiplied by the following correction factor when glycol-based fluids are used:

For 20-30% concentrations: correction factor = 0.9

Appendix F: Calculation Of Dewpoint Temperature

The dewpoint temperature of the air is the temperature at which the air contains all the water vapor it can hold. If air is cooled below its current dewpoint temperature, some moisture will condense as liquid water on whatever surface is cooling the air. The formation of condensate on the coil of a chilled water air handler is an example. If a radiant panel surface is cooled to or below the dewpoint temperature, condensation will also form on its surface. This is very undesirable since these radiant panels are interior room surfaces. Thus, it is common practice to operate a radiant cooling panel at a minimum water temperature that is at least 2° or 3°F above the current dewpoint temperature of the room.

The dewpoint temperature of air depends on its dry-bulb temperature as well as its relative humidity. Anything that causes either of these parameters to change will also change the current dewpoint temperature.

Formulas F-1 through F-4 can be used to calculate the current dewpoint temperature based on the current dry-bulb temperature and relative humidity of the air:

Formula F-1

$$T_{db(^\circ C)} = \frac{T_{db(^\circ F)} - 32}{1.8}$$

Formula F-2

$$B = \frac{\ln\left(\frac{RH}{100}\right) + \left(\frac{17.27\left(T_{db(^\circ C)}\right)}{237.3 + T_{db(^\circ C)}}\right)}{17.27}$$

Formula F-3

$$T_{dew(^\circ C)} = \left(\frac{237.3B}{1 - B}\right)$$

Formula F-4

$$T_{dew(^\circ F)} = 1.8\left(T_{dew(^\circ C)}\right) + 32$$

Where:

$T_{db(^\circ F)}$ = current dry-bulb temperature of room air (ºF)
RH = current relative humidity of room air (%)

Example: The measured conditions in a room are as follows:

- dry-bulb temperature = 76ºF
- relative humidity = 60%

Determine the current dewpoint temperature of the room air:

Solution: Use Formulas F-1 through F-4 in order.

Formula F-1

$$T_{db(^\circ C)} = \frac{T_{db(^\circ F)} - 32}{1.8} = \frac{76 - 32}{1.8} = 24.4^\circ C$$

Formula F-2

$$B = \frac{\ln\left(\frac{RH}{100}\right) + \left(\frac{17.27\left(T_{db(^\circ C)}\right)}{237.3 + T_{db(^\circ C)}}\right)}{17.27} = \frac{\ln\left(\frac{60}{100}\right) + \left(\frac{17.27(24.4)}{237.3 + 24.4}\right)}{17.27} = 0.06366$$

Formula F-3

$$T_{dew(^\circ C)} = \left(\frac{237.3(B)}{1 - B}\right) = \left(\frac{237.3(0.06366)}{1 - 0.06366}\right) = 16.13^\circ C$$

Formula F-4

$$T_{dew(^\circ F)} = 1.8\left(T_{dew(^\circ C)}\right) + 32 = 1.8(16.13) + 32 = 61.0^\circ F$$

Thus, any surface within this room at a temperature less than 61.0ºF would start to accumulate condensation. The lower the surface temperature relative to the dewpoint temperature, the faster this condensation will accumulate.

GeoCal™ geothermal manifolds

series 110

CALEFFI

(shown with optional valves)

Function

The GeoCal™ pre-assembled manifold for ground-source geothermal loops offers an alternative method of piping parallel earth loops, bringing all circuits to a common manifold station without labor-intensive fusion welding. GeoCal manifolds provide significant installation, commissioning, and operational advantages. With optional ¾" or 1" QuickSetter™ balancing valves with flowmeters and shutoff ball valves, GeoCal allows easy individual circuit balancing leading to lower pumping costs and greater system efficiency. Shutoff ball valves installed on the return manifold allows for easy individual circuit purging while minimizing purge pump size. GeoGrip™ couplings are used for connecting to polyethylene piping, either directly to the manifold or to the balancing valves and shutoff valves, making the ground earthloop installation completely free of fusion joints.

GeoCal™ pre-assembled manifold for ground-source geothermal loops, with automatic air vents, dual-scale temperature gages, fill/drain valves, supply and return manifolds, brass end caps with insulation, wall brackets with mounting hardware and labels

Product range

Series 110 GeoCal™ pre-assembled manifold ....2 to 8 earthloop circuit outlets 1-1/4" NPT female end connection

Technical specification

Materials:

Supply and Return manifold body: polymer PA66G30
End fitting with air vent, fill/drain cock: brass
End cap: brass
Tie rods: stainless steel
Wall mounting brackets: stainless steel

Performance:

Suitable fluids: water, ethanol*, methanol*, glycol and saline solutions
Max. percentage of solutions:
- glycol: 50%
- ethanol: 30%
- methanol: 25%

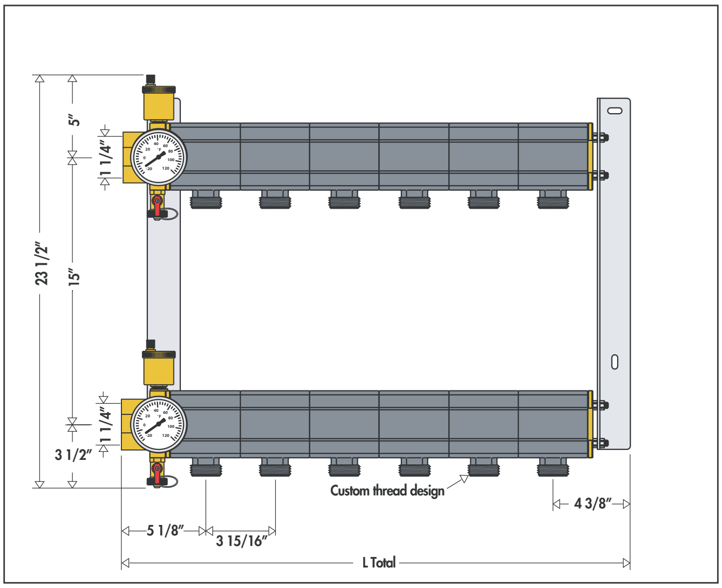
Max. working pressure: 90 psi (6 bar)
Max. system test pressure: 150 psi (10 bar)
Working temperature range:
- water, glycol and saline solutions: 15 –140°F (-10 – 60°C)
- ethanol and methanol solutions: 15 – 85°F (-10 – 30°C)

Ambient temperature range: -5 – 140°F (-20 – 60°C)
Max. flow rate: 24 gpm (1.6 l/s) total all circuits
Supply & Return manifold end connection: 1-1/4" NPT female
Connection center distance: 4 inch (100 mm)
Custom threaded circuit connections with EPDM mechanical seal for connecting geothermal pipe fitting, shutoff ball valves, or QuickSetter balancing valves.
*Always verify compliance with local regulations prior to use.

Product codes

Code	Description			
1107B5LA	1-1/4" NPT end	GeoCal™ Manifold	2 circuits	Left side Pipe Connections
1107C5LA			3 circuits	
1107D5LA			4 circuits	
1107E5LA			5 circuits	
1107F5LA			6 circuits	
1107G5LA			7 circuits	
1107H5LA			8 circuits	
1107B5RA	1-1/4" NPT end	GeoCal™ Manifold	2 circuits	Right side Pipe Connections
1107C5RA			3 circuits	
1107D5RA			4 circuits	
1107E5RA			5 circuits	
1107F5RA			6 circuits	
1107G5RA			7 circuits	
1107H5RA			8 circuits	

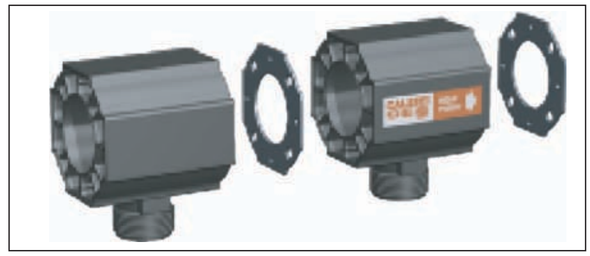
Dimensions



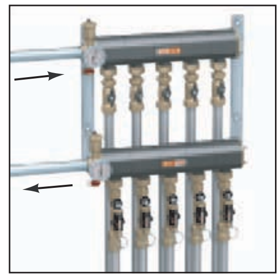
Code (Left/Right)	No. Outlets	L Total	Weight (lb)
1107B5LA/5RA	2	13 1/4”	16.6
1107C5LA/5RA	3	17 1/4”	18.2
1107D5LA/5RA	4	21 1/4"	19.8
1107E5LA/5RA	5	25 1/4”	21.5
1107F5LA/5RA	6	29 1/4”	23.1
1107G5LA/5RA	7	33 1/4”	24.8
1107H5LA/5RA	8	37 1/4”	26.4

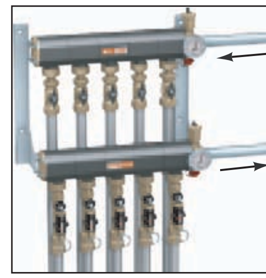
Construction details

The manifold modules have been designed to prevent condensation. Polymer construction with an air gap insulating the medium from outside humidity reduces the effficts of exterior corrosion.

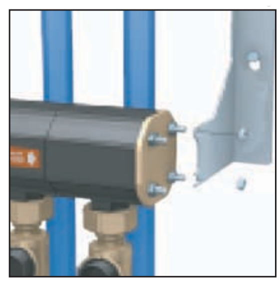


The manifold is reversible providing installation flexibility for easy connection to the earthloops with respect to the heat pump.



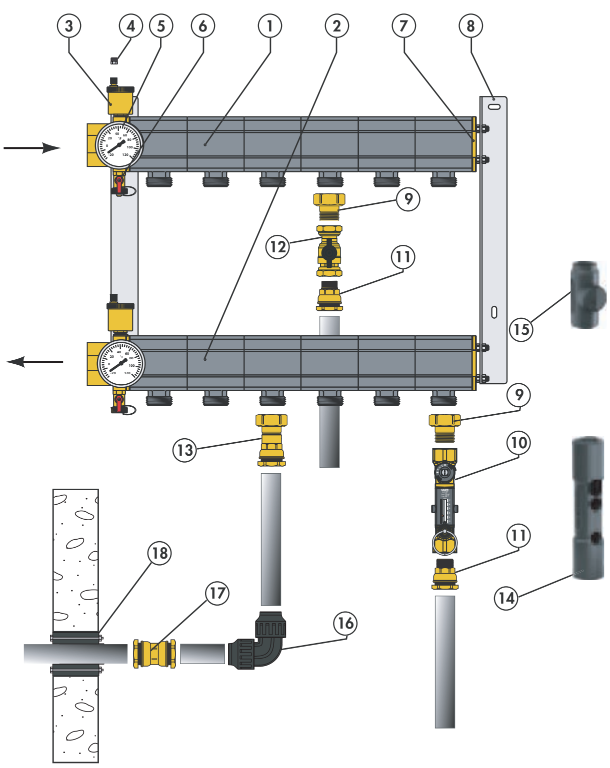


Two brass end caps and four tie-rods compress the modules to ensure proper sealing. The seal between the modules isolates the internal fluid duct and the single air chambers.



The bracket can be mounted to a wall before mounting the manifold to allow for easy connection to the earthloops.

Characteristic Components



1. Supply manifold
2. Return manifold
3. Air vent
4. Vent cap adapter NA10204 (for methanol/ethanol fluids)
5. Temperature gage
6. Drain valve
7. Blind end plug
8. Bracket
9. Manifold outlet fitting 110050A/60A*
10. QuickSetter 132552A/662A*
11. GeoGrip pipe coupling 861527A/634A*
12. Isolation valve NA39589/NA39753*
13. GeoGrip manifold to earthloop pipe connector NA10246/247*
14. Optional insulation shells for QuickSetters with inlet/outlet fittings 112001/003*
15. Optional insulation shells for isolation valves with inlet/outlet fittings 111001/003*
16. GeoGrip elbow NA866027/034*
17. GeoGrip sleeve coupling 863027/034*
18. GeoSeal Wall penetration seal NA10248/NA10249*

* Part numbers for 3/4” / 1” sizes

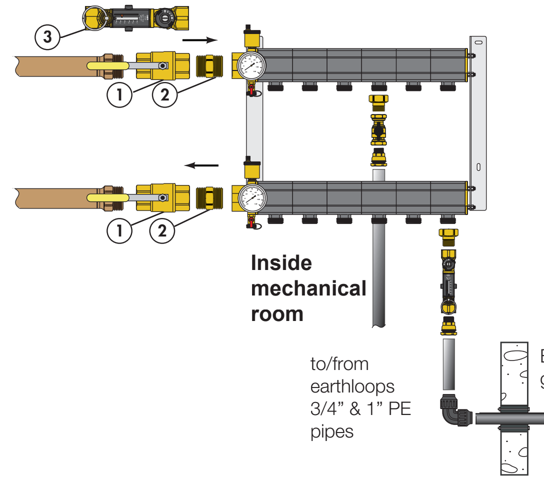
Flexible pipe connection choices:

A. Connect directly to earthloop piping using item 13.
B. Connect using isolation valves with items 9,11,12.
C. Connect using QuickSetters with items 9,10,11.

GeoGrip™ and GeoSeal™ fittings for pipe in main heat pump circuit supply and return lines

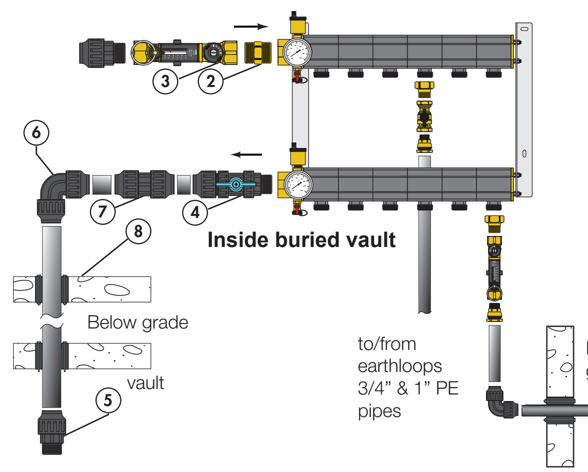
Inside mechanical room installation

To isolate the manifold and connect directly to the heat pump with metal pipe, use ball valve (1) with double nipple (2) on both heat pump circuit supply and return ports. The QuickSetter balancing valve with flowmeter (3) can replace the ball valve on the supply line combining isolation valve and flow setting. In addition, the QuickSetter (3) provides a way to measure the total ground heat exchanger flowrate which, along with supply and return temperatures read from the manifold temperature gages, can be used to calculate the heat suppled by the earthloop system.



Outside buried vault installation

To isolate the manifold and connect to the heat pump with buried PE pipe, use ball valve (4) with double nippled (2) on the heat pump circuit supply and return ports. Alternatively, brass ball valve (1) can be installed with double nipple (2) and male adapter (5) to connect to PE pipe. Additional GeoGrip fittings are available to complete the piping layout to the heat pump in the mechanical room: elbow coupler (6), sleeve coupler (7), and GeoSeal wall penetration seal (8). See previous page for 3/4" and 1" GeoGrip and GeoSeal fittings for the earthloop circuits. The QuickSetter balancing valve with flowmeter (3) can replace the ball valve on the supply line combining isolation valve and flow setting and calculating the heat suppled by the earthloop system.



GeoGrip™ and GeoSeal™ fittings for 1-1/4" pipe in heat pump circuit main supply and return lines

GeoGrip mechanical fittings for connecting HDPE geothermal piping. The GeoSeal wall penetration seal is ideal for connecting ground earthloop systems to heat pumps through concrete walls.

Product range

Code NA39588	Ball valve with lever, 1-1/4" NPT female brass	1
Code NA10263	Double nipple, 1-1/4" NPT brass	2
Code 132772A	QuickSetter balancing valve with flowmeter, 1-1/4" NPT female brass	3
Code 132882A	QuickSetter balancing valve with flowmeter, 1-1/2" NPT female brass	3
Code NA10268	GeoGrip ball valve with T-handle, 1-1/4" NPT male x PE pipe compression	4
Code NA10269	GeoGrip male adapter, 1-1/4" NPT x PE pipe compression	5
Code NA866042	GeoGrip elbow coupling, 1-1/4" x 1-1/4" PE pipe compression	6
Code NA863042	GeoGrip pipe sleeve coupling, 1-1/4" x 1-1/4" PE pipe compression	7
Code NA10265	GeoSeal 1-1/4" wall penetration seal	8

Technical specification

For all GeoGrip fittings items 4-7:

Body and lock nut:	Polypropylene
O-ring:	EPDM
Clenching ring:	Polyacetal resin

Suitable fluids: water, 50% max. glycol solutions, 25% max. methanol solutions, 30% max. ethanol solutions, saline solutions

Max. working pressure:	230 psi (16 bar)
Max. working temperature:	140°F (60°C)

QuickSetter™ Balancing valve with flow meter series 132

Function

QuickSetter balancing valves allow setting the flow rate in earthloop circuits without requiring calibration equipment. Flow adjustment is performed with the system running using a simple
3 step process: 1) pull by-pass circuit pin; 2) while viewing site gage, turn stem to adjust flow to desired value; 3) release by-pass circuit pin. Flow gage is hermetically sealed from flow stream thus preventing scaling and clouding of glass. By-pass circuit prevents debris from affecting flow accuracy. To facilitate circuit purging and filling, the QuickSetter also serves as an isolation valve when adjustment stem is fully turned clockwise.

Technical specification

Valve & flowmeter body, and ball	brass
Ball control stem & bypass valve stem:	brass, chrome-plated
Ball seal seat:	PTFE
Control stem guide & flowmeter float & indicator cover:	PSU
Flowmeter springs:	stainless steel
Seals:	PDM E
Suitable fluids:	water, 50% max. glycol solutions, 25% max. methanol solutions, 30% max. ethanol solutions, saline solutions
Max. working pressure:	150 psi (10 bar)
Max. temperature:	230°F(110°C)
Accuracy:	±10%
Flow rate correction factor for 20%-30% glycol solutions:	0.9

Product range

Code 132552A	2.0 - 7.0 GPM	3/4” NPT
Code 132662A	3.0 - 10.0 GPM	1” NPT
Code 132772A	5.0 - 19.0 GPM	1 1/4” NPT
Code 132662A	8.0 - 32.0 GPM	1 1/2” NPT

Isolation shutoff ball valves series NA39

Function

These full port ball valves with blow-out proof stem are used with the GeoCal manifold to isolate geothermal earthloop circuits for purging and filling. If a circuit becomes unusable for any reason, it can be shut off and isolated from the rest of the system,

Technical specification

Valve body:	brass
Ball:	brass, chrome-plated
Seats, seals and thrust washer:	PTFE
Suitable fluids:	water, 50% max. glycol solutions, 25% max. methanol solutions, 30% max. ethanol solutions, saline solutions
Max. working pressure:	150 psi (10 bar)
Max. temperature:	365°F (185°C)

Product range

Code NA39589	Ball valve with T-handle, 3/4” NPT female
Code NA39753	Ball valve with T-handle, 1” NPT female
Code NA39588	Ball valve with lever, 1-1/4” NPT female

GeoGrip™ and GeoSeal™ fittings for HDPE pipe

Function

GeoGrip mechanical fittings with o-ring seals are high quality compression-style fittings used for connecting HDPE geothermal piping. The GeoSeal wall penetration seal forms a water-tight mechanical seal between the pipe and the hole it passes through, ideal for connecting ground earthloop systems to heat pumps through concrete walls.

Product range

Code 110050A	3/4” NPT male to GeoCal manifold	9
Code 110060A	1” NPT male to GeoCal manifold	
Code 861527A	GeoGrip 3/4” HDPE pipe x 3/4” NPT male	11
Code 861634A	GeoGrip 1” HDPE pipe x 1” NPT male	
Code NA10246	GeoGrip 3/4” HDPE pipe to GeoCal manifold	13
Code NA10247	GeoGrip 1“ HDPE pipe to GeoCal manifold	
Code NA866027	GeoGrip 3/4” x 3/4” HDPE pipe elbow coupling	16
Code NA866034	GeoGrip 1” x 1” HDPE pipe elbow coupling	
Code 863027	GeoGrip 3/4” x 3/4” HDPE pipe sleeve coupling	17
Code 863034	GeoGrip 1” x 1” HDPE pipe sleeve coupling	
Code NA10248	3/4” wall penetration seal	18
Code NA10249	1” wall penetration seal	

Technical specification

GeoGrip fittings except 90° elbow:

Body and lock nut:	brass
Seal:	NBR

NA866027 and NA866034 90° elbow:

Body and lock nut:	Polypropylene
O-ring:	EPDM
Clenching ring:	Polyacetal resin
Suitable fluids:	water, 50% max. glycol solutions, 25% max. methanol solutions, 30% max. ethanol solutions, saline solutions
Max. working pressure:	230 psi (16 bar)
Max. working temperature:	140°F (60°C)


11


16


9


17


13


18

DISCALDIRT® air & dirt separator

series 546

Air and dirt separators are used to continuously remove the air and debris contained the hydronic circuits of heating and cooling systems. The air discharge capacity of these devices is very high. They are capable of automatically removing all of the air present in the system down to micro-bubble level. The DISCALDIRT® air and dirt separator also separates any solid impurites in teh system. The impurities collect at the bottom of the device and can be removed through the drain shut-off cock. The circulation of fully de-aerated and cleaned water enables the equipment to operate under optimum conditions, free fro noise, corrosion, localized or mechanical damage.

Product range

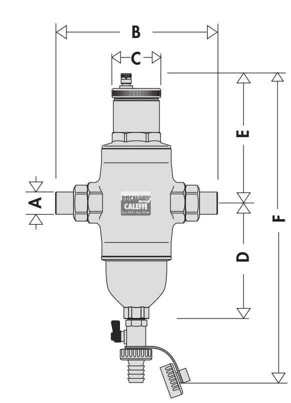
546 series DISCALDIRT air and dirt separator in brass................sizes 3/4” and 1” sweat union
546 series DISCALDIRT air and dirt separator in brass................size 1” NPT male union
546 series DISCALDIRT air and dit separator in brass................size 1 1/4” sweat

Technical specifications

Materials:
- Body: brass
- Dirt separation chamber: brass
- Automatic air vent body: brass
- Internal element: PA66GF30
- Float: PP
- Float guide: brass
- Stem: brass
- Float lever: stainless steel
- Spring: stainless steel
- Seals: EPDM
- Drain shut-off valve: brass

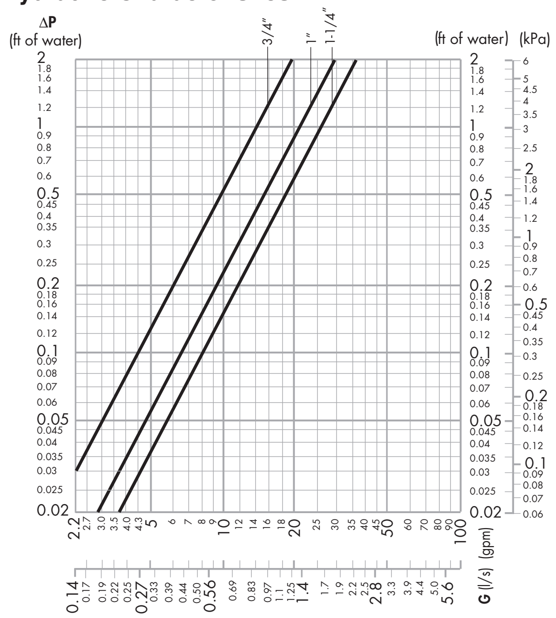
Suitable fluids: water, 50% max. glycol solutions, 25% max. methanol solutions, 30% max. ethanol solutions, saline solutions
Max working pressure: 150 psi (10 bar)
Temperature range: 32–230°F (0 –110°C)
Particle separation capacity: 5 μm (0.2 mil)
Connections:
- Main: 3/4” and 1” sweat union, 1” NPT male union, 1 1/4” sweat
- Drain valve: hose connection

Dimensions



Code	Connections	A	B	C	D	E	F	Weight (lb)
546095A	Sweat union	3/4”	6 -3/8”	2 -1/8”	5”	5 -1/2”	12 - 3/4”	8.3
546096A	Sweat union	1”	7 -3/8”	2 -1/8”	5”	5 -1/2”	12 - 3/4”	8.3
546016A	NPT union	1”	7 -3/8”	2 -1/8”	5”	5 -1/2”	12 - 3/4”	8.3
546097A	Sweat	1-1/4”	6 -3/16”	2 -1/8”	5”	5 -1/2”	12 - 3/4”	8.3

Hydraulic Characteristics



Flow capacity

The fluid velocity at connections for DISCALDIRT 546 series air and dirt separators is recommended to not exceed 10.0 f/s. Above this speed, heavy internal turbulence and noise can occur and air and dirt elimination efficiency begins to fall measurably. Optimal air and dirt elimination performance occurs at fluid velocities of 4.0 f/s or less. See the flow capacity chart.

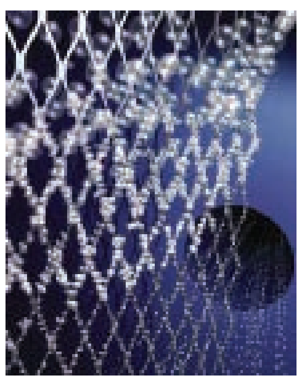
		FLOW CAPACITY		
	Size	3/4"	1"	1-1/4"
Optimal (≤4.0 f/s)	GPM	8.0	9.3	10.0
	l/s	0.5	0.6	0.63
Max. (10.0 f/s)	GPM	19.0	22.1	25.0
	l/s	1.2	1.4	1.6
	Cv	19.1	32.5	40.0

Operating Principle

Microbubble air separation

The DISCALDIRT's internal element (1) creates the whirling movement required to facilitate the release of microbubbles and their adhesion to the internal element surfaces.

The bubbles, fusing with each other, increase in size until the hydrostatic thrust overcomes the adhesion force to the mesh. They rise toward the top of the unit from which they are released through a float-operated automatic air vent.

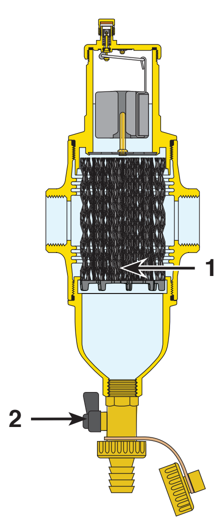


Microparticle dirt separation

Impurities in the fluid upon striking the surfaces of the DISCALDIRT's internal element (1), get separated and drop to the bottom of the body where they collect.

In addition, the large internal volume of DISCALDIRT slows down the flow speed of the fluid thus helping, by gravity, to separate the particles it contains.

The collected impurities are discharged by opening the drain valve (2) with the handle, even with the system operating.



The process of air formation

The amount of air which can remain dissolved in a water solution is a function of pressure and temperature. This relationshiop is governed by Henry's law, which says the amount of air released by the solution increases with temperature rise and pressure reduction. The comes in the form of micro-bubbles of diameters in the order of tenths of a millimeter. In heating and cooling systems there are specific points where this process of formation of micro-bubbles takes place continously in the boiler and in any device which operates under conditions of cavitation.

Dirt separation efficiency

The capacity for separating the impurities in the medium circulating in the closed circuits of hydronics systems and geothermal earthloop systems basically depends on three parameters:

1) It increases as the size and mass of the particle increase. The larger and heavier particles drop before the lighter ones.

2) It increases as the speed decreases. If the speed decreases, there is a calm zone inside the dirt separator and the particles separate more easily.

3) It increases as the number of recirculations increases. The medium in the circuit, flowing through the dirt separator a number of times during operation, is subjected to a progressive action of separation, until the impurities are completely removed.

The special design of the internal element in the Caleffi DISCALDIRT air and dirt separator is able to completely separate the impurities in the circuit down to a minimum particle size of 5 μm (0.2 mil).

DISCAL® air separator

series 551

CALEFFI

Function

Air separators are used to continuously remove the air contained in the hydronic circuits of heating and cooling systems. The air discharge capacity of these devices is very high. They are capable of removing automatically all the air present in the system down to micro-bubble level.

The circulation of fully de-airated water enables the equipment to operate under optimum conditions, free from any noise, corrosion, localized overheating or mechanical damage. Micro-bubbles, fusing with each other, increase in volume (get larger) until they become large enough to rise to the top where they are automatically released.

Product range

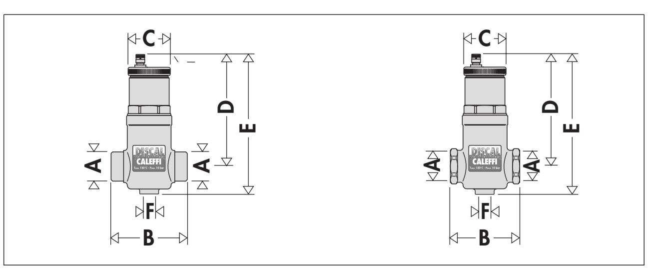
Series 551 DISCAL air separator in brass compact with drain..Sizes 3/4” sweat; 3/4” NPT female
Series 551 DISCAL air separator in brass with drain............................ Sizes 3/4”, 1”, 1-1/4”, 1-1/2” & 2” NPT female; 1”, 1-1/4”, 1-1/2” & 2” sweat
561402A Check valve, 1/2” for brass DISCAL to mount expansion tank..1/2” NPT
NA10204 Vent cap adapter to connect discharge tube for geothermal systems using methanol and ethanol solutons......................1/4” NPT male

Technical specifications

Materials:

Body:	brass
Internal element (compact version):	stainless steel
Internal t: elemen	PA66GF30
Seal:	EPDM

Dimensions:



Code	A	B	C	D	E	F	Weight (lb)
551022A	3/4”	3 1/16”	2 3/16”	5 5/8”	6 7/8”	1/2”	2.0
551003A	3/4” swt	3 1/16”	2 3/16”	5 5/8”	6 7/8”	1/2”	2.0

Add suffix C to code number when ordering Discal to ship with expansion tank check valve, code 561402A.

Performance:

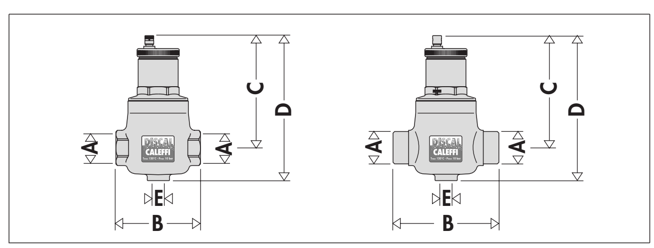
Suitable fluids: water, 50% max. glycol solutions, 25% max. methanol solutions, 30% max. ethanol solutions, saline solutions

Max. working pressure: 150 psi (10 bar)

Temperature range: 32 – 250°F (0 – 120°C)

Connections: -Main: compact series: 3/4” sweat; 3/4” NPT female
3/4”, 1”, 1-1/4”, 1-1/2” & 2” NPT female
1”, 1-1/4”, 1-1/2” & 2” sweat

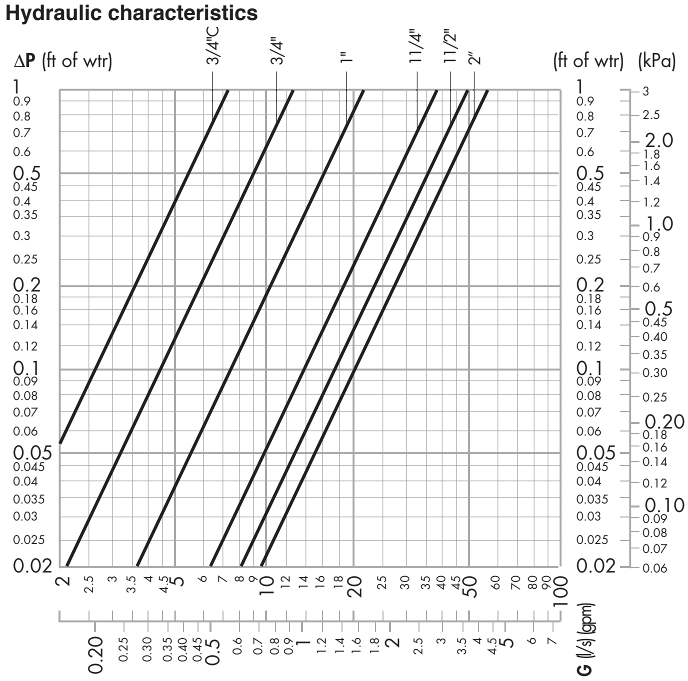
-Drain: 1/2” NPT female



Code	A	B	C	D	E	Weight (lb)
551005A	3/4”	4 5/16”	5 3/4”	7 1/2”	1/2”	3.7
551006A	1”	4 5/16”	5 3/4”	7 1/2”	1/2”	3.7
551007A	1 1/4”	4 7/8”	6 9/16”	8 1/4”	1/2”	4.9
551008A	1 1/2”	4 7/8”	6 9/16”	8 1/4”	1/2”	4.9
551009A	2”	5 1/8”	6 9/16”	8 1/4”	1/2”	4.9
551028A	1” swt	5 1/16”	5 3/4”	7 1/2”	1/2”	3.7
551035A	1 1/4” swt	5 3/16”	6 5/16”	8 1/4”	1/2”	3.7
551041A	1 1/2” swt	5 3/4”	6 9/16”	8 1/4”	1/2”	4.9
551054A	2” swt	6 1/8”	6 9/16”	8 1/4”	1/2”	5.5

idronics

Hydraulic characteristics



The fluid velocity at connections for Discal 551 series air separators is recommended to not exceed 10.0 f/s. Above this speed, heavy internal turbulence and noise can occur and air elimination efficiency begins to fall measurably. Optimal air elimination performance occurs at fluid velocities of 4.0 f/s or less. See the flow capacity chart.

		Flow Capacity					
	Size	3/4" C	3/4"	1"	1 1/4"	1 1/2"	2"
Optimal	GPM	6.0	8.0	9.3	15.3	23.9	36.1
(≤4.0 f/s)	L/ Sec.	0.4	0.5	0.6	1.0	1.5	2.3
Max	GPM	14.3	19.0	22.1	36.4	56.8	86.0
(≤10.0 f/s)	L/ Sec.	0.9	1.2	1.4	2.3	3.6	5.4
	Cv	11.6	19.1	32.5	56.4	73.1	81

Accessories

Check valve code 561402A for expansion tanks. 1/2" NPT connections.

Hygroscopic safety vent cap code R59681.

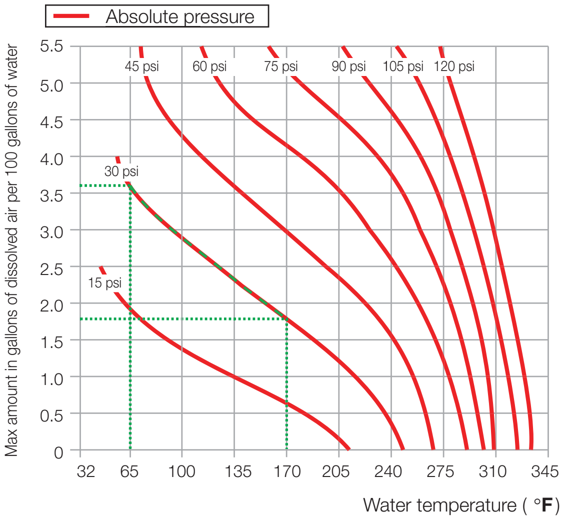
Small anti-vacuum vent cap code 562100.

Replacement Discal air vent cap code 59119.

Vent cap adapter for discharge tube, code NA10204.

The process of air formation

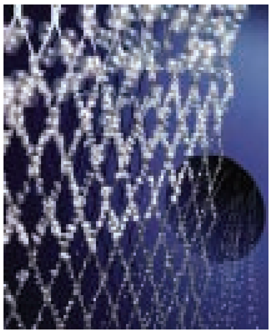
The amount of air which can remain dissolved in a water solution is a function of pressure and temperature.
This relationship is governed by Henry's Law and the graph below demonstrates the physical phenomenon of the air release from water. As an example, at a constant absolute pressure of 30 psi (2 bar), if the water is heated from 65°F (18°C) to 170°F (75°C), the amount of air released by the solution is equal to 1.8 gallons of air per 100 gallons of water.
According to this law it can be seen that the amount of air released increases with temperature rise and pressure reduction. The air comes in the form of micro-bubbles of diameters in the order of tenths of a millimeter.
In heating and cooling systems there are specific points where this process of formation of micro-bubbles takes place continuously: in the boiler and in any device which operates under conditions of cavitation.

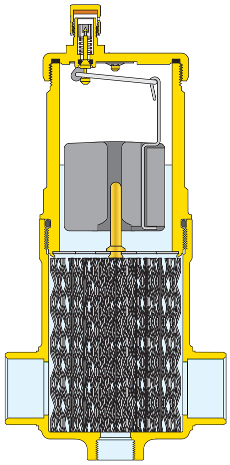


Operating principle

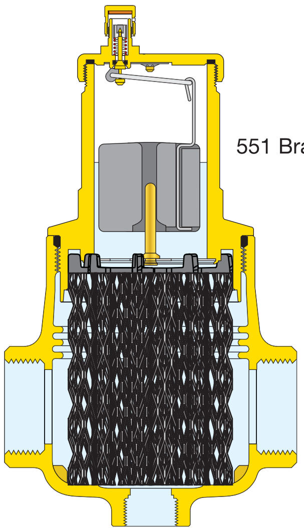
The air separator uses the combined action of several physical principles. The active part consists of an assembly of concentric mesh surfaces. These elements create the whirling movement required to facilitate the release of micro-bubbles and their adhesion to these surfaces.

The bubbles, fusing with each other, increase in size until the hydrostatic thrust overcomes the adhesion force to the mesh. They rise towards the top of the unit from which they are released through a float-operated automatic air release valve.





551 Compact series



551 Brass series

DIRTCAL® dirt separator

5462 series

Function

In heating and air conditioning control systems, the circulation of water containing impurities may result in rapid wear and damage to components such as pumps and control valves. It also causes blockages in the heat exchangers, heating elements and pipes, resulting in a lower thermal efficiency within the system.
The dirt separator separates off these impurities, which are mainly made up of particles of sand and rust, collecting them in a large collection chamber, from which they can be removed even while the system is in operation.
This device is capable of efficiently removing even the smallest particles, with extremely limited head loss.
Patented.

Product range

5462 Series DIRTCAL dirt separator with NPT threaded connections .... sizes 3/4”–1-1/2”
5462 Series DIRTCAL dirt separator with sweat connections .... sizes 1”, 1-1/4”, 1-1/2” & 2”

Technical specifications

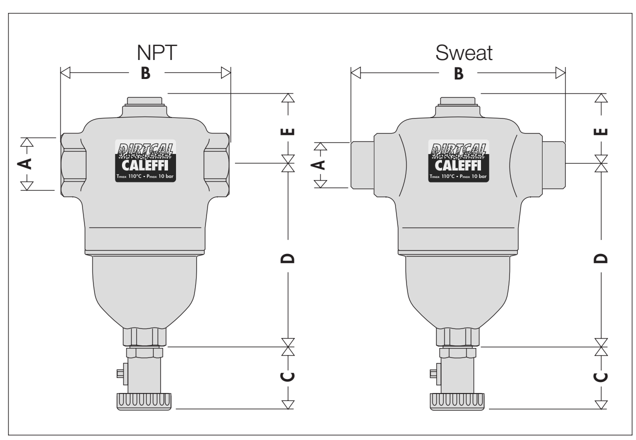
Materials:
- body: brass
- dirt collection chamber: brass
- top plug: brass
- internal element: PA66G30
- hydraulic seals: EPDM
- drain cock: brass

Suitable fluids:
- water & glycol solutions: 50% max.
- water & methanol solutions: 25% max.
- water & ethanol solutions: 30% max.
- water & saline solutions: 30% max.

Max working pressure: 150 psi (10 bar)
Temperature range: 32 – 250º F (0 –110°C)
Particle separation capacity: to 5 μm

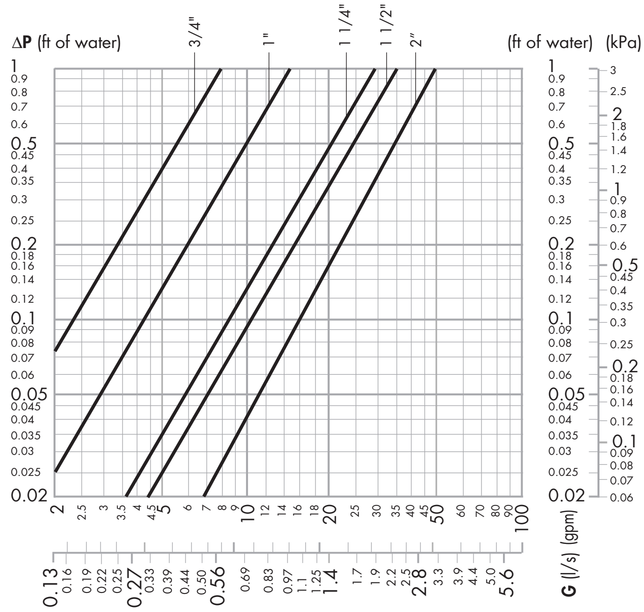
Connections:
- main: 3/4”, 1”, 1 1/4”, 1 1/2” NPT
  1” -1 1/4” - 1 1/2” - 2” sweat
- top: 1/2” F (with plug)
- drain: 3/4” garden hose

Dimensions



Code	A	B	C	D	E	Weight (lb)
546205A	3/4″ NPT	4 5/16″	1 1/4″	5″	2″	4.2
546206A	1″ NPT	4 5/16″	1 1/4″	5″	2″	4.2
546207A	1 1/4″ NPT	4 7/8″	1 1/4″	6″	2″	5.3
546208A	1 1/2″ NPT	4 7/8″	1 1/4″	6″	2″	5.3
546209A	2″ NPT	5 1/8″	1 1/4″	6″	2″	5.3
546228A	1″ Sweat	5 1/16″	1 1/4″	5″	2″	4.2
546235A	1 1/4″ Sweat	5 3/16″	1 1/4″	6″	2″	4.2
546241A	1 1/2″ Sweat	5 3/4″	1 1/4″	6″	2″	4.9
546254A	2″ Sweat	6 1/8″	1 1/4″	6″	2″	5.5

Hydraulic Characteristics



The maximum fluid velocity recommended at the unit connections is ~ 4.0 f/s. The following table shows the recommended flow rates to comply with this condition.

	Flow Capacity				
Size	**3/4"**	**1"**	**1 1/4"**	**1 1/2"**	**2"**
GPM	6.0	9.3	15.3	23.9	36.0
L/sec.	0.4	0.6	1.0	1.5	2.3
Cv	18.8	32.6	56.6	73.3	81.0

Separation efficiency

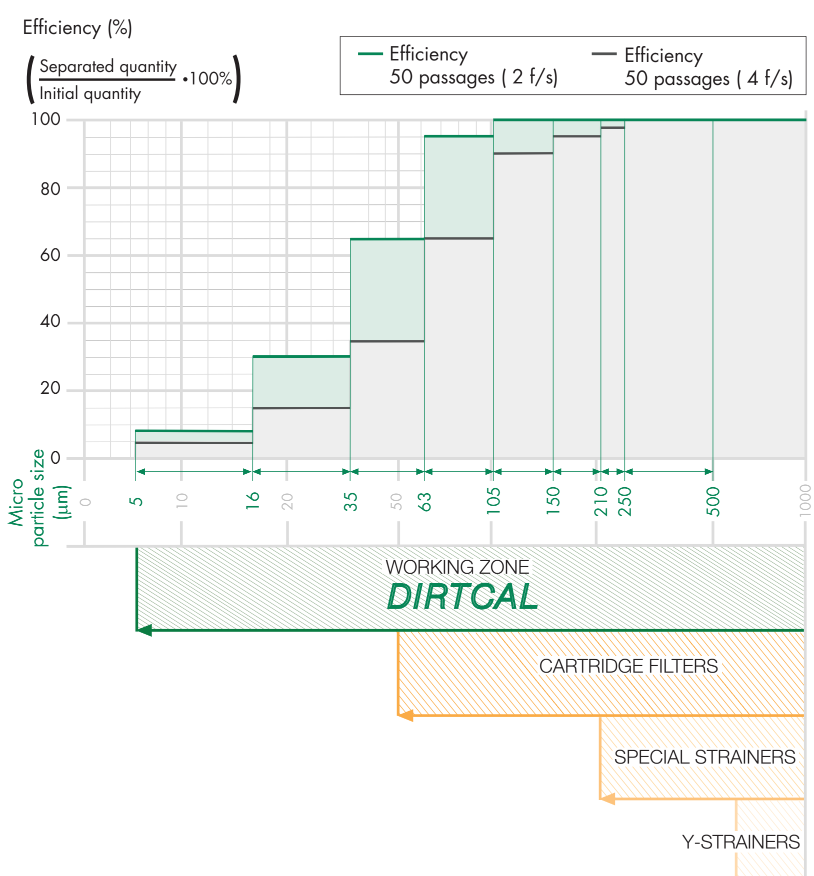
The capacity for separating the impurities in the medium circulating in the closed circuits of the systems basically depends on three parameters:

1) It increases as the size and mass of the particle increase. The larger and heavier particles drop before the lighter ones.

2) It increases as the speed decreases. If the speed decreases, there is a calm zone inside the dirt separator and the particles separate more easily.

3) It increases as the number of recirculations increases. The medium in the circuit, flowing through the dirt separator a number of times during operation, is subjected to a progressive action of separation , until the impurities are completely removed.

The special design of the internal element in the Caleffi DIRTCAL dirt separator is able to completely separate the impurities in the circuit down to a minimum particle size of 5 µm (0.2 mil). The adjacent graph illustrates how DIRTCAL quickly separates nearly all the impurities. After only 50 recirculations, approximately one day of operation, up to 100% is effectively removed from the circuit for particles of diameter greater than 100 µm (3.9 mil) and on average up to 80% taking account of the smallest particles. The continual passing of the medium during normal operation of the system gradually leads to complete dirt removal.



Reduced head losses

A normal Y strainer performs its function via a metal mesh selected for the size of the largest particle. The medium therefore has a consequent initial loss of head that increases as the degree of clogging increases. Whereas, the dirt separator carries out its action by the particles striking the internal element and subsequently dropping into the collection chamber. The consequent head losses are greatly reduced and are not affected by the amount of impurities collected.

ThermoCon™ storage tanks

series NAS200

Function

ThermoCon tanks are designed to be used for solar and geothermal storage, plus in heating systems with low-mass boilers, chilled water systems and low-mass radiation. ThermoCon tanks are used in systems operating below the design load condition, which is most of the time, or in systems having several low cooling or heating loads demands at different times. Boilers operating at low loads will short cycle, resulting in reduced operating efficiency and shorter equipment life. When piped correctly, the ThermoCon will serve as both a thermal buffer and a hydraulic separator. The solar, boiler or chiller system will be hydraulically separated from the distribution system.

The ThermoCon tanks are engineered with seven (7) 2” NPT connections. Two connections can be piped to the solar, boiler or chiller side and two connections can be piped to the distribution system. Two additional connection are 90 degree from another which allows for positioning tank into a corner with the piping at a right angle. The tank has one 2” NPT connection for connecting an external heat exchange in the middle of the tank.

Meets and exceeds CSA C309 requirements

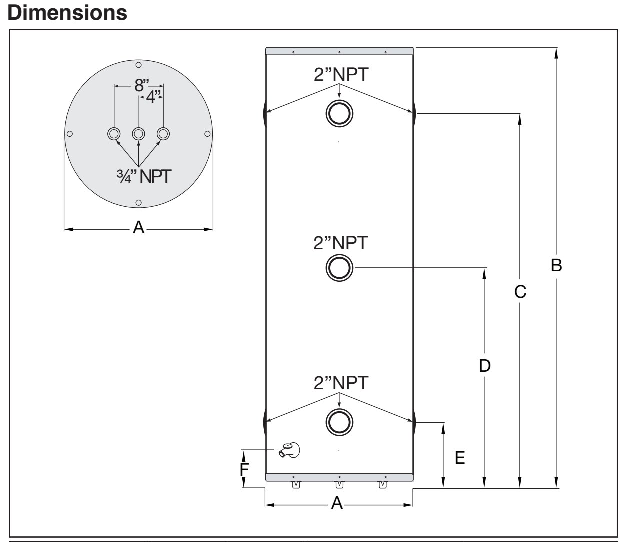
Product range

NAS20050	Storage tank	50 gallon
NAS20080	Storage tank	80 gallon
NAS20120	Storage tank	120 gallon

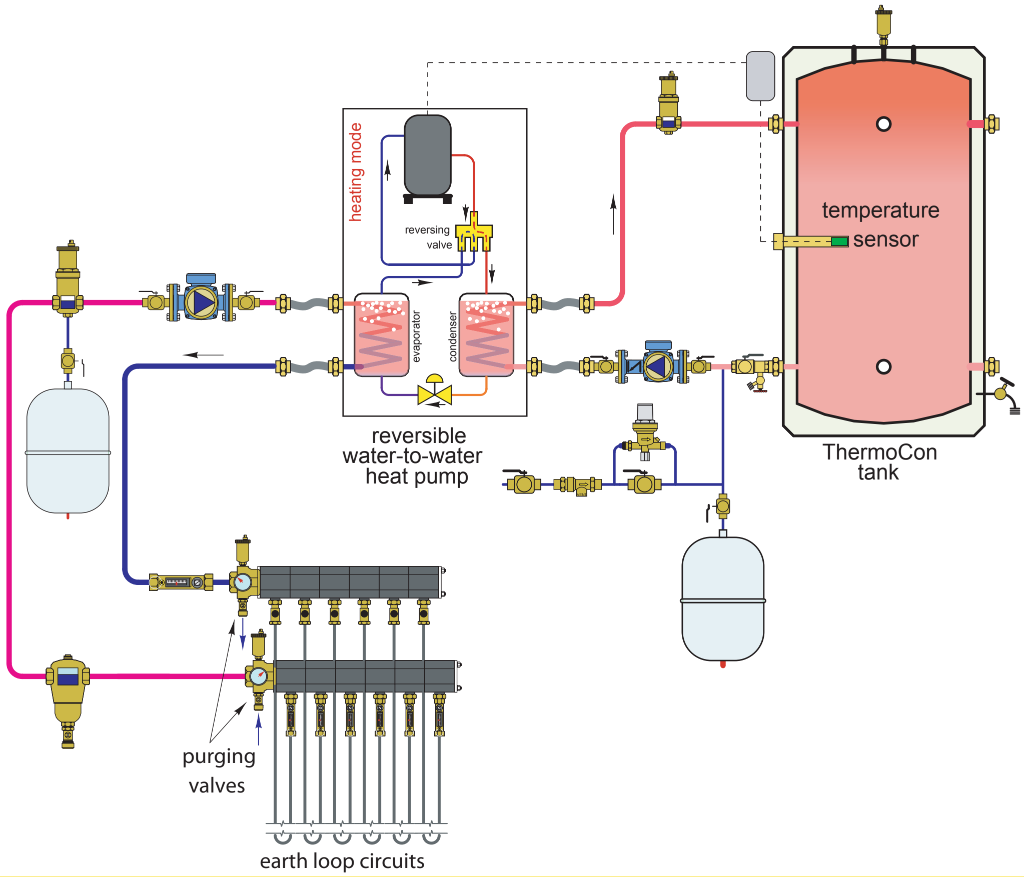
Technical specifications

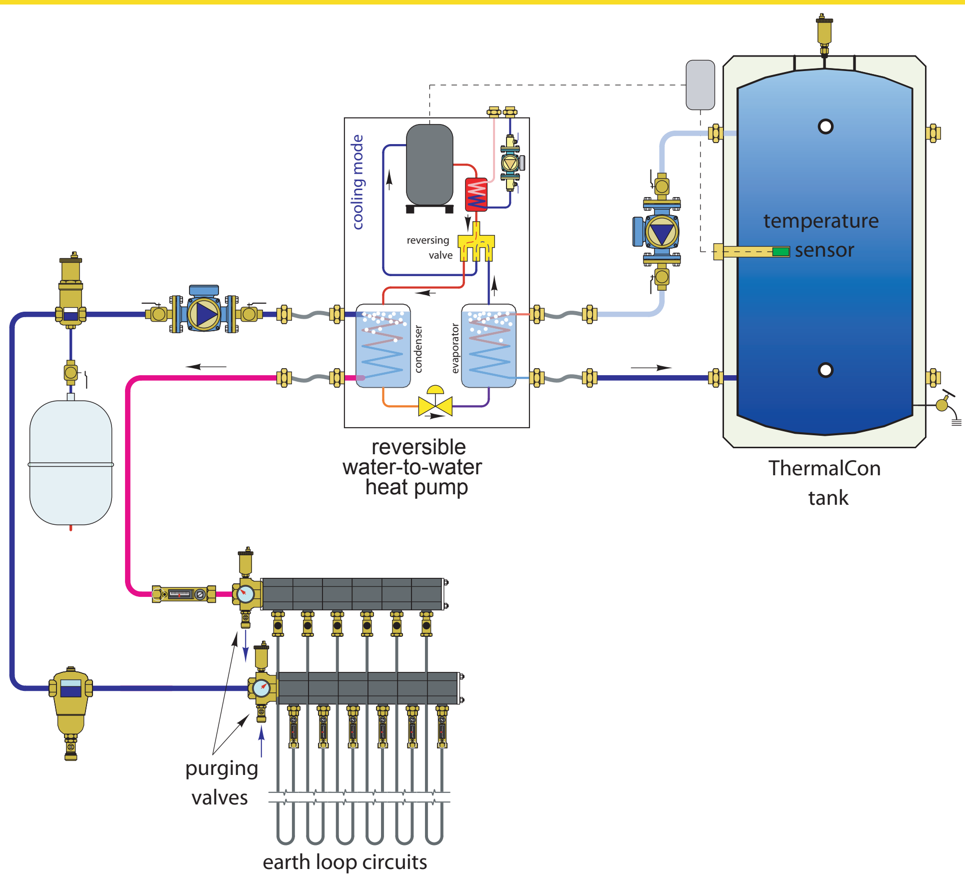
Tank materials:	porcelain coated steel
Tank insulation:	2" non-CFC foam
Tank external cover:	powder-coated steel (20-24 ga.)
Insulation thermal conductivity:	R16
Connections:	top (3) 3/4" NPT female side (7) 2” NPT female
Maximum working pressure:	150 psi
Testing pressure:	300 psi
Maximum tank temperature:	180°F
Recommended maximum delivery hot water temperature:	120°F

Dimensions



Model	A	B	C	D	E	F
NAS20050	22”	48¼”	39½”	23½”	7¾”	4½”
NAS20080	24”	64”	53”	32”	11”	5”
NAS20120	28”	65”	53”	32”	11”	7”


heating mode
reversing valve
evaporator
condenser
reversible water-to-water heat pump
temperature sensor
ThermoCon tank
purging valves
earth loop circuits


cooling mode
reversing valve
condenser
evaporator
reversible water-to-water heat pump
temperature sensor
ThermalCon tank
purging valves
earth loop circuits

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