Small-Scale Hydronic Cooling

Hydronic technology has long been known for providing unsurpassed heating comfort. Indeed, the vast majority of the hydronic systems now installed in homes and light-commercial buildings provide space heating, and in some cases, domestic water heating. Few currently provide cooling.

This has led consumers and heating professionals to believe that hydronic technology is only applicable to heating, and that a separate system is needed if space cooling is desired.

Fortunately, advances in modern hydronic technology, as well as those associated with devices such as hydronic heat pumps, now stand ready to change this perception.

The same physical properties that make water ideal for conveying heat also make it ideal for conveying cooling. Cooling is just the removal of heat. Water can absorb 3,467 times as much heat as a cubic foot of air for the same temperature change. This implies that chilled water circulated through some type of "terminal unit" is ideal for absorbing heat from occupied space. It can do this using tubing that is much smaller than equivalent ducting.

Engineers who design commercial, industrial and institutional buildings have long understood the benefits of chilled-water cooling systems in comparison to "all-air" systems. Many large buildings contain a central plant in which refrigeration equipment known as chillers reduce the temperature of water into the range of 40º to 50ºF. This water is circulated through insulated piping to all areas of the building, where it eventually passes through various terminal units to absorb heat and condense water vapor from the building's air.

Now it's time to scale the highly successful use of chilled-water cooling in larger buildings for use in smaller buildings, such as single and multifamily homes and light-commercial structures. This publication will introduce you to the emerging market for small-scale hydronic cooling.

Before getting into hardware specifics, let's discuss what it has to offer.

Benefits of Chilled-Water Cooling

• **Minimally invasive installation:** The ability of water to absorb almost 3,500 times more heat than the same volume of air has profound implications for the size of the piping required to convey chilled water through a building in comparison to the size of ducting required to move a thermally equivalent amount of air through that building.

Here's an example: A 3/4-inch tube carrying chilled water at a flow rate of 6 gallons per minute through a terminal unit that warms the water stream by 15ºF as it absorbs heat is conveying 45,000 Btu/hr. To do this with a duct operating at a face velocity of 1,000 feet per minute and an air temperature change of 30ºF requires a cross-section of 240 square inches. This translates to a 20-inch-wide by 12-inch-deep duct, or an 18-inch-round duct, as shown in Figure 1. Either of these ducts would be difficult to conceal within the framing cavities of residential and light-commercial buildings.

Figure 1

3/4" copper tube carrying water = 10" x 21" duct carrying air = 16.5" duct carrying air
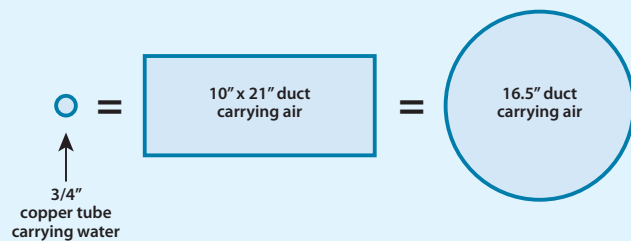
The usual compromise is to "conceal" the ducting behind soffits, as shown in Figure 2.

Figure 2

Source: http://angthebuilder.blogspot.com

Although many homeowners reluctantly accept such soffits as necessary because forced-air heating and cooling is being used, those soffits unquestionably compromise the aesthetics of finished interior spaces. They also add to building cost, decrease headroom, and in some cases, limit how the space can be used.

• **Reduced electrical energy usage:** A properly designed chilled-water distribution system uses significantly less electrical energy compared to a forced-air distribution system of equivalent thermal capacity. This difference can best be compared by calculating the *distribution efficiency,* which is defined by Formula 1:

Formula 1

$$\text{Distribution efficiency} = \frac{\text{rate of heating or cooling delivery (Btu/hr)}}{\text{power input to distribution system (watt)}}$$

Distribution efficiency is totally determined by the system used to distribute heat (or chilled water) through the building. It has nothing to do with the thermal efficiency at which that heat (or chilled water) was produced. Thus, it provides a convenient way to compare forced-air versus hydronic distribution systems. It can also be used to compare the efficiency of one hydronic distribution system to another.

Here's an example: Published data for the blower in a geothermal water-to-air heat pump using forced-air delivery indicates that a 3/4-horsepower motor is required to deliver approximately 1,500 CFM airflow. The estimated electrical power supplied to this motor when operating at full capacity is 690 watts. The rated total cooling capacity of this unit is about 53,000 Btu/hr (based on 60°F entering water temperature). The heat pump's distribution efficiency *under these conditions is:*

$$\text{Distribution efficiency} = \frac{53,000 \text{ Btu/hr}}{690 \text{ watts}} = 76.8 \ \frac{\text{Btu/hr}}{\text{watt}}$$

This means that the forced-air distribution system is delivering 76.8 Btu/hr of thermal energy transfer for each watt of electrical power supplied to operate it. By itself, this number is not very useful. However, it provides a *relative* measure of performance when compared to the distribution efficiencies of other distribution systems, either forced-air or hydronic.

For example, assume that a hydronic circuit of equal heat delivery capacity consists of 200 feet of 1" copper tubing. It will operate with a 15°F chilled-water temperature rise (45° to 60°F) across the terminal unit. It uses a standard wet rotor circulator with an assumed 22% wire-to-water efficiency. The fan in the terminal unit has a high-efficiency motor with a power input of 75 watts at full speed.

The water flow rate required for delivering 53,000 Btu/hr at a 15°F temperature change is:

$$f = \frac{Q}{500 \text{ x } \Delta T} = \frac{53,000}{500 \text{ x } 15} = 7.0 gpm$$

Assuming a 200-foot total equivalent length for the circuit, the pressure drop in the circuit is 5.2 psi. The power supplied to the circulator under these operating conditions can be estimated using Formula 2:

Formula 2

$$w = \frac{0.4344 \text{ x } f \text{ x } \Delta P}{e}$$

Where:
w = electrical input power to circulator (watts)
f = flow rate through circulator (gpm)
ΔP = pressure increase across circulator (psi)
e = wire-to-water efficiency of circulator (decimal %)

For the assumed chilled-water distribution system, the estimated electrical power supplied to the circulator is:

$$w = \frac{0.4344 \text{ x } f \text{ x } \Delta P}{e} = \frac{0.4344 \text{ x } 7 \text{ x } 5.2}{0.22} = 71.9 watt$$

The distribution efficiency of this hydronic system can now be calculated using Formula 1. Note that the power input to the circulator (71.9 watts) as well as to the fan in the terminal unit (75 watts) is included in this calculation:

$$\text{Distribution efficiency} = \frac{53,000 \text{ Btu/hr}}{(71.9 + 75) \text{ watts}} = 361 \ \frac{\text{Btu/hr}}{\text{watt}}$$

This comparison shows that the chilled-water distribution system only requires about 21% of the electrical power required by an equivalent forced-air distribution system. The savings associated with this difference in power requirement over several years of operation can be substantial.

High distribution efficiency is especially important in cooling systems. That's because _all the electrical energy supplied to move either chilled air or chilled water through a cooling distribution system ultimately ends up as heat dissipated within the building_. Thus, the total cost of electricity to operate the system includes the cost of electricity to operate the blowers, fans, or circulators in the distribution system, _plus the additional electricity needed by the cooling source to capture and remove the heat added to the building by the blowers, fans, or circulators._

If the blower in a forced-air heat pump system rated at 53,000 Btu/hr of total cooling capacity requires 690 watts of electrical power, this adds 2,355 Btu/hr (or about 0.2 tons) to the building's cooling load.

The total electrical power requirement to operate the cooling distribution system, and dissipate the heat it produces can be estimated using Formula 3:

Formula 3

$$P_{total} = P_d \left[\frac{3.413}{EER} \right]$$

Where:
P_{total} = total power required to operate the cooling distribution system _(including the parasitic heat it produces)_ (watt)
P_d = power required to operate the cooling distribution hardware (watt)
EER = Energy Efficiency Ratio of the cooling source (Btu/hr/watt)

Here's an example: Assume a well-designed chilled water distribution system could operate with a total power input (including circulators and fans as calculated in the previous example) of 146.9 watts. The chiller providing the chilled water operates at an EER of 18. The total electrical power required to operate the distribution system _and_ dissipate its associated heat gain would be:

$$P_{total} = P_d \left[1 + \frac{3.413}{EER} \right] = 146.9 \left[1 + \frac{3.413}{18} \right] = 175 watt$$

By contrast, the total electrical power required to operate a forced air system distribution driven by a blower requiring 690 watts, with a cooling source operating at the same EER of 18, would be:

$$P_{total} = P_d \left[1 + \frac{3.413}{EER} \right] = 690 \left[1 + \frac{3.413}{18} \right] = 821 watt$$

The higher the electrical power requirement of the cooling distribution system, and the lower the EER of the cooling source, the greater the total power demand required to maintain comfort.

The savings associated with using the chilled water distribution system instead of the forced air distribution system cited in the previous example is substantial.

For example: Assume that each of the previously described cooling distribution systems operates for 1,000 hours per year in a location where electricity costs $0.15 per kilowatthour. The first year estimated savings of the chilled water distribution system over the forced air distribution system would be:

$$\left(\frac{821 - 175 watt}{1} \right) \left(\frac{1000 hr}{yr} \right) \left(\frac{1 kwhr}{1000 whr} \right) \left(\frac{\$0.15}{kwhr} \right) = \frac{\$97}{yr}$$

The accumulated savings over time can be calculated using formula 4:

Formula 4

$$\text{Accumulated savings} = (\text{1st year of savings}) \left(\frac{(1 + i^N) - 1}{i} \right)$$

Where:
i = rate of inflation (decimal %)
N = years over which savings accumulate

For the example systems cited, and assuming electrical rates increase by 3 percent per year, the total savings accumulated over 20 years would be:

$$\text{Accumulated savings} = (\$97) \left(\frac{(1 + 0.03^{20}) - 1}{0.03} \right) = \$2,606$$

This is a very significant savings, especially considering that this comparison is for a _residential_ scale cooling system.

• **Availability of chillers:** Every chilled-water cooling system obviously needs a source of chilled water. Absent a deep well with suitable water quality, or a lake close to the building to be cooled, chilled water is likely to be produced mechanically using a vapor-compression refrigeration cycle. Devices that use this cycle are often referred to as chillers.

There are many options for chillers that can be used in smaller chilled-water cooling systems. Examples include non-reversible water-to-water heat pumps and air-cooled condenser units, as well as reversible heat pumps. The latter category includes water-to-water geothermal heat pumps and air-to-water heat pumps.

Of these, _the air-to-water heat pump option is by far the less complex and costly option._ Advances in refrigeration technology have significantly increased the thermal performance of air-to-water heat pumps in recent years. _During heating mode, some air-to-water heat pumps can now operate at outdoor temperatures below 0°F and with seasonal coefficient of performance (COP)_

values that approach those of geothermal heat pump systems. This type of reversible air-to-water heat pump will be the assumed chiller (as well as heat source) for the systems discussed in this publication.

• **No coil frosting:** Many air handlers and fan coils used for cooling have direct expansion (e.g., "DX") coils. Liquid refrigerant flows into these coils and evaporates as it absorbs heat from the airstream passing across the coil. In some cases, the temperature of the refrigerant within the coil can be lower than 32ºF. This allows frost to form on the coil. This frost decreases heat transfer between the airstream and the coil surface, which reduces performance.

Frost formation is more likely on DX coils that have insufficient airflow passing through them. This is often caused by improperly sized ducting or zone dampers that close in the distribution system without a corresponding change in refrigerant flow through the coil.

These problems will not occur in a coil supplied by chilled water. The lowest chilled-water temperature that is normally supplied to such a coil is approximately 40ºF. Higher chilled-water temperatures in the range of 45º to 60ºF may also be useful depending on the moisture-removal requirements. Although proper duct sizing and airflow regulation in zoned forced-air systems is still necessary, airflow rates that are slightly lower than design requirements will not create coil frosting.

• **Easy zoning:** Chilled-water cooling systems are very easy to zone. Multiple-zone cooling systems allow for different temperatures in various areas of a building. They also provide the potential to reduce operating cost since unoccupied areas don't have to be maintained at normal comfort temperature and humidity levels, even when other areas of the building do require cooling. For example, sleeping areas can be maintained at comfortable temperatures and humidity levels on hot and humid summer nights, while areas such as laundry rooms, recreation rooms or storage areas receive minimal, if any, cooling.

There are several possible ways to zone chilled-water cooling systems. One approach uses a separate circulator to control flow to each zone. When this approach is used, it's important to verify that the circulators being considered are rated for use with chilled water. Circulators that are not compatible with fluid temperatures down to 35ºF should not be used for chilled-water distribution systems.

Zoning can also be achieved using electrically operated zone valves in combination with variable-speed pressure-regulated circulators. Figure 3 shows this concept.

This approach will generally lower the electrical power required by the distribution system relative to use of several zone circulators.

Figure 3

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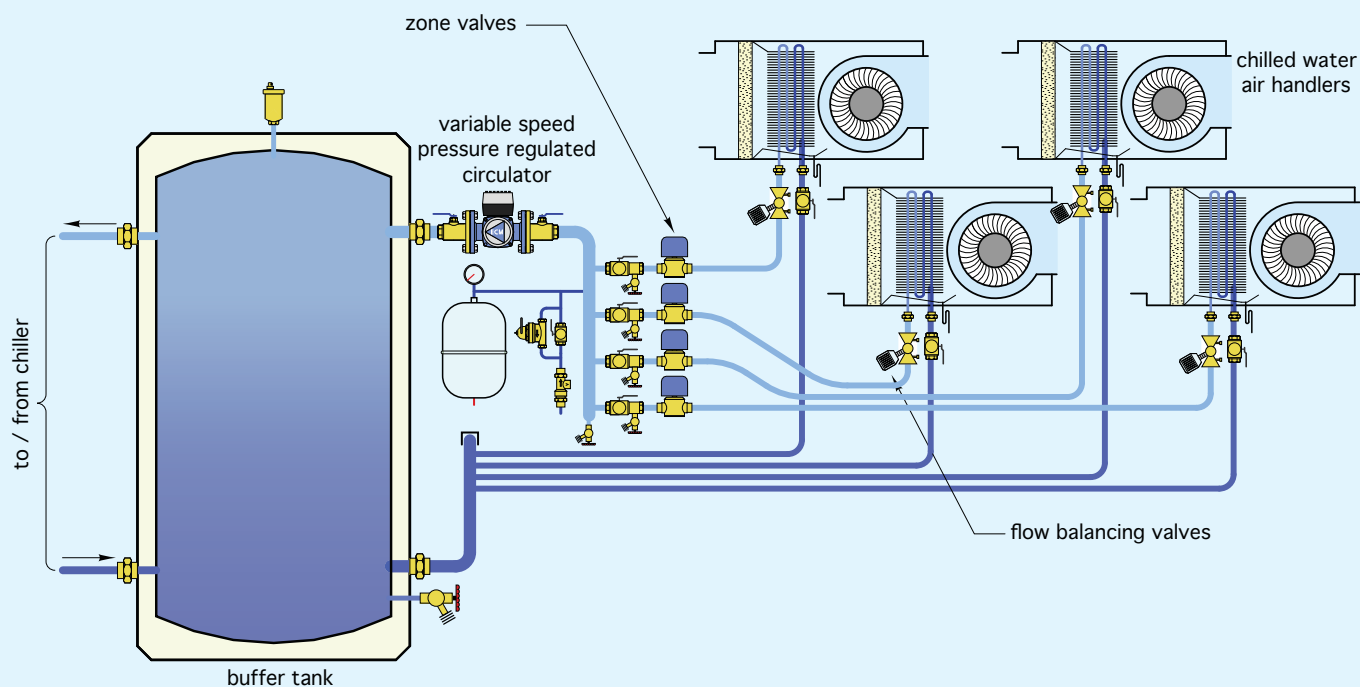
• **Radiant panel cooling:** Chilled water can also be used for radiant-panel cooling. Ceiling surfaces with embedded hydronic tubing are ideal for absorbing heat from the occupied space below. An example of a radiant ceiling that can provide both heating and radiant cooling is shown, under construction, in Figure 4.

Figure 4

The chilled water supplied to a radiant panel must remain above the dewpoint temperature of the room it serves. This prevents water vapor in the air from condensing on the panel surface. Methods for doing this will be described shortly. This constraint only allows a radiant panel to handle the sensible portion of the total cooling load (e.g., cooling the air without removing moisture from it). Other equipment is required to handle the latent portion of the cooling load (e.g., moisture removal).

• **Chilled-beam cooling:** Chilled beams are specially designed terminal units that use chilled water at temperatures above the room's dewpoint to create gentle cooling airflow within a room using natural convection. Although relatively new to North America, chilled beams have been used in European buildings since the 1970s. Like radiant ceiling panels, they can only satisfy the sensible portion of the cooling load, and thus must be used in combination with other hardware that manages moisture removal. Figure 5 shows a typical chilled-beam installation in a suspended ceiling grid.

Figure 5

• **Lower refrigerant volume:** Chilled-water cooling systems contain far less refrigerant and are more adaptable than direct expansion (DX) or variable refrigerant flow (VRF) cooling systems. This is important for several reasons.
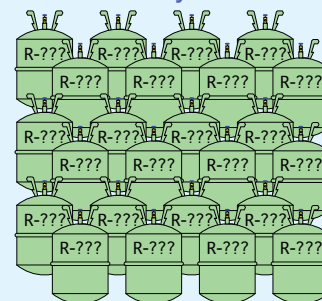
First, a leak in a commercial VRF system could mean the loss of many pounds of refrigerant. Not only is this expensive, it also releases gases that create a safety hazard within the building. The refrigerants currently used in VRF systems, if released, also contribute to climate change.

Figure 6
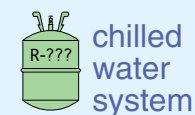
Second, the refrigerants and oils used in current generation VRF systems may not be the same as those used in the future. There is no guarantee that a currently installed VRF system will be compatible with future refrigerants or oils. Incompatibility could require a major changeout in equipment, piping and terminal units. By comparison, chilled-water distribution systems are not reliant on specific refrigerants and their associated piping and lubrication requirements. Chilled-water distribution systems will remain compatible with future chillers, and thus ensure that major disruptions of the building to modify piping and terminal units will not be required.

Third, water-based systems allow for thermal storage, which is not feasible with DX or VRF systems. In some applications, the use of thermal storage allows chiller operation to be shifted to "off-peak" hours when the cost of electricity is substantially reduced.

Fourth, chilled-water distribution systems are adaptable to non-electrically powered chillers, such as gas-fired absorption chillers, earth loop heat exchangers, and in some cases, cool water from lakes or deep wells.

Fifth, chilled-water systems can make use of several polymer-based piping materials, such as PEX and polypropylene. These piping products are less expensive and generally easier to install than the all-copper piping systems required with DX or VRF systems.

Finally, chilled water is adaptable to technology such as radiant-panel cooling and chilled beams, which require far less electrical energy to distribute cooling through the building relative to VRF systems.

• Thermal storage: Chilled-water cooling is adaptable to thermal storage where preferential time-of-use electrical rates or ambient temperatures make this approach feasible. One example of a system that leverages thermal storage is shown in Figure 7.

The heat pump transfers energy to a large and very well-insulated thermal storage tank. In heating mode, the tank is warmed. In cooling mode, the tank is chilled. Thermal energy is then transferred between this tank and the load as required.

Thermal storage allows an air-to-water heat pump to operate during the most favorable outdoor conditions. When providing cooling, the heat pump can operate at night when outdoor temperatures are lower and there is no solar heat generation. This allows the heat pump to achieve higher cooling capacity and higher efficiency. Nighttime operation also coincides with most "off-peak" electrical rate offerings from utility companies, which further reduces operating cost.

In the common situation where the heating load of a building exceeds the cooling load, the use of adequate thermal storage allows the heat pump to be sized for the full design heating load, without concern over short cycling during cooling mode operation.

Thermal storage also allows for extensive zoning of the distribution system where necessary, without concern for short cycling the heat pump.

A properly configured thermal storage tank can also serve as a hydraulic separator between multiple circulators within the system.
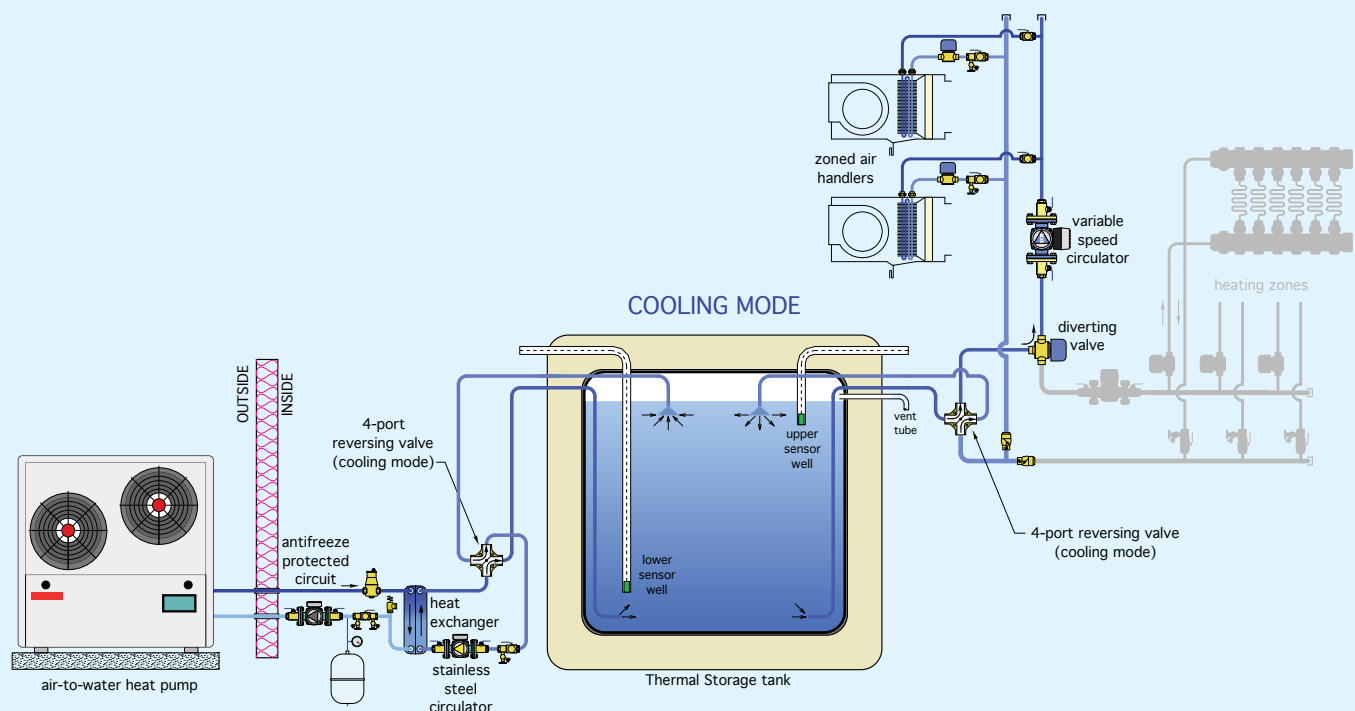
Air-to-Water Heat Pumps

The ability of water to absorb almost 3,500 times more heat than the same volume of air has profound implications for the size of the piping required to convey chilled water through a building in comparison to the size of ducting required to move a thermally equivalent amount of air through that building.

An air-to-water heat pump uses outside air as either the source of low-temperature heat (when operating in heating mode) or as the "sink" to which heat is rejected (when operating in cooling mode).

During the heating mode, an air-to-water heat pump adds heat to a stream of water (or a mixture of water and antifreeze) that circulates between the heat pump and the remainder of a hydronic distribution system.

Figure 7

COOLING MODE

Thermal Storage tank

When operating in cooling mode, an air-to-water heat pump absorbs heat from the stream of water (or a mixture of water and antifreeze), thus cooling it for use in a chilled-water cooling system.

Figure 8 shows two examples of modern air-to-water heat pumps.

Figure 8

These heat pumps are placed outside, and relatively close to the buildings they serve. Insulated supply and return pipes connects the heat pump to the remainder of the hydronic system inside the building.

Figure 9 is a simplified illustration of the main internal components in an air-to-water heat pump.

This air-to-water heat pump uses a standard vapor compression refrigeration cycle to move low-temperature heat to regions of higher temperature.

When operating in cooling mode, liquid refrigerant enters a refrigerant-to-water heat exchanger which serves as the evaporator of the refrigerant cycle. The cold liquid refrigerant

Figure 9


air-to-water heat pump
(in cooling mode)
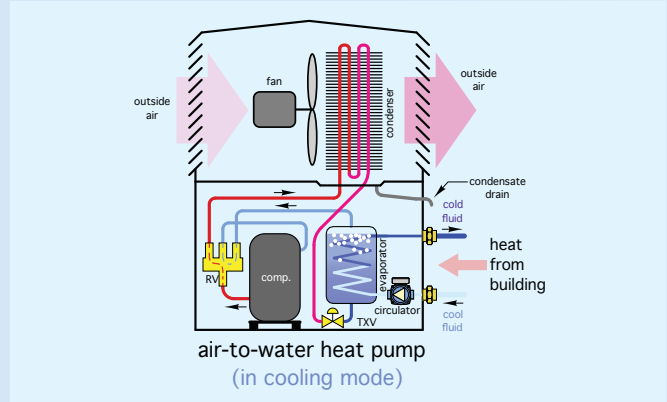
absorbs heat from the water circulated through this heat exchanger. This absorbed heat causes the refrigerant to vaporize. The vaporized refrigerant then flows through the reversing valve, which directs the refrigerant onward to the compressor. Within the compressor, the pressure and temperature of the refrigerant vapor is greatly increased. The high-pressure/higher temperature refrigerant vapor then flows to a refrigerant-to-air heat exchanger that serves as the condenser of the refrigeration cycle. Outside air is forced across this heat exchanger by one or more fans. Heat transfers from the hot refrigerant vapor to the passing airstream, and is carried out of the heat pump. This loss of heat causes the refrigerant to condense back to a liquid. It then flows on to a thermal expansion valve, where its pressure and temperature are reduced to the point where it is ready to repeat this cycle.

The useful result of this process is a stream of chilled water, typically in the range of 40° to 60°F, which will be distributed throughout the building for cooling and dehumidification.

Figure 10 shows how an air-to-water heat pump might be connected to a hydronic system that provides both chilled-water cooling and warm-water heating.

Figure 10
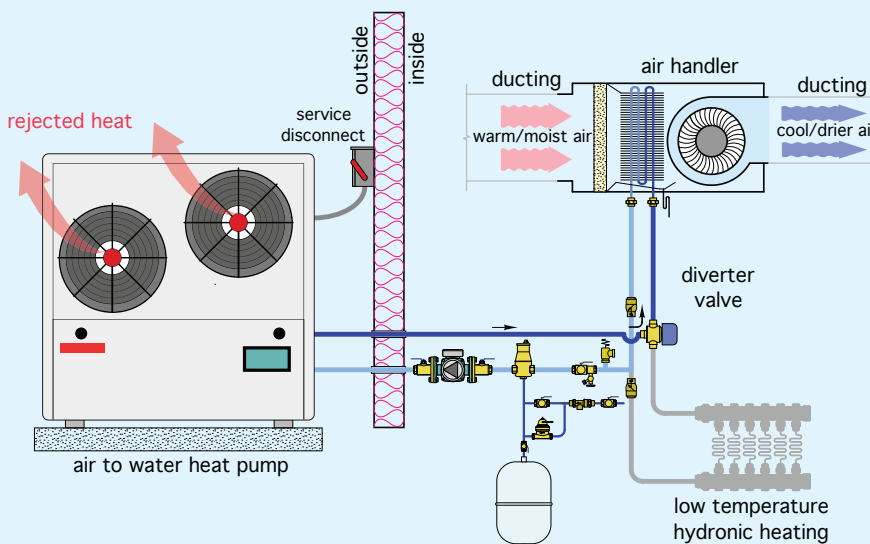
This system circulates water between the heat pump and the interior portions of the system. This approach is generally acceptable in warm climates that experience minimal, if any, freezing conditions. However, in most North American locations it is necessary to protect the heat pump and its associated outdoor piping from freezing. This can be done two ways:

1. Fill the entire system with an antifreeze solution.

2. Install a high-efficiency heat exchanger between the heat pump and the remainder of the system, and use an antifreeze solution in the circuit connecting the heat pump to this heat exchanger. Water can then be used in the remainder of the system.

A piping system using the latter option is shown in Figure 11.

Figure 11

air to water heat pump
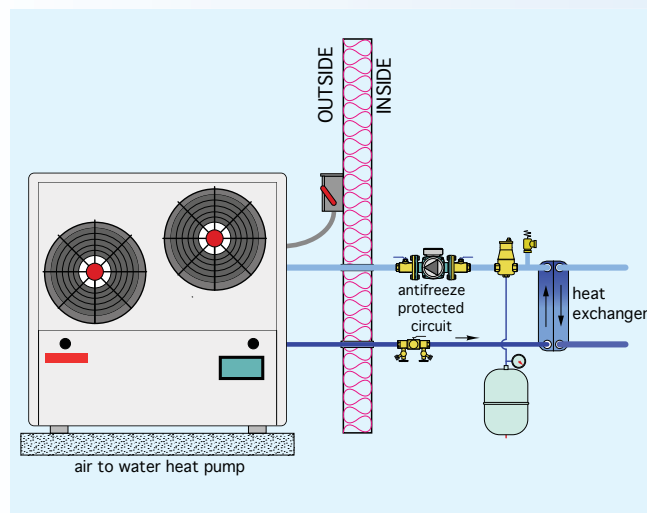
The first option (e.g., filling the entire system with an antifreeze solution) is more often used in smaller systems with relatively low total system volume.

The second option (e.g., installing a heat exchanger) is more often used in larger systems, or systems with thermal storage tanks, where the total system volume is much greater.

Figure 12 shows an example of a brazed-plate stainless steel heat exchanger that could be used to separate the antifreeze solution from water in this application. This type of heat exchanger is readily available and easily sized using software.

Figure 12

Courtesy of GEA PHE systems

Heat exchangers should always be piped so that the two fluid streams pass through them in opposite directions. This is called "counterflow" heat exchange. It produces the highest average temperature difference between the two fluids, and thus allows the highest possible rate of heat exchange.

When a heat exchanger is used between the heat pump and the remainder of the system, it's also important to minimize the temperature differential between the antifreeze solution on one side and the water on the other side. This difference is called the "approach temperature difference" of the heat exchanger. Figure 13 shows how it is defined and measured.

Figure 13

maximum approach temperature difference (cooling)

$<= 5°F$

from chiller   to load
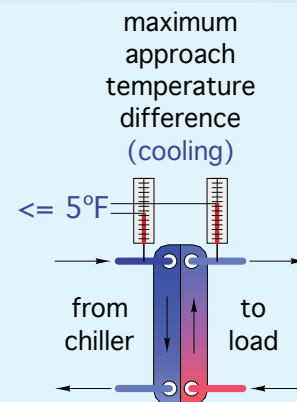
To maintain good cooling performance, the maximum suggested approach temperature difference between the antifreeze stream coming to the heat exchanger from the heat pump and the chilled water stream leaving the heat exchanger is 5ºF. Even lower approach temperature differences are better if achievable through larger heat exchangers.

Cooling Performance of Air-to-Water Heat Pumps:
The ability of an air-to-water heat pump to chill water depends on several operating conditions. The most influential are the water temperature entering the heat pump's evaporator, and the temperature of outdoor air entering the heat pump's condenser. Figure 14 shows an example of how outdoor temperature and the temperature of water leaving the heat pump affects its cooling capacity.

Figure 14
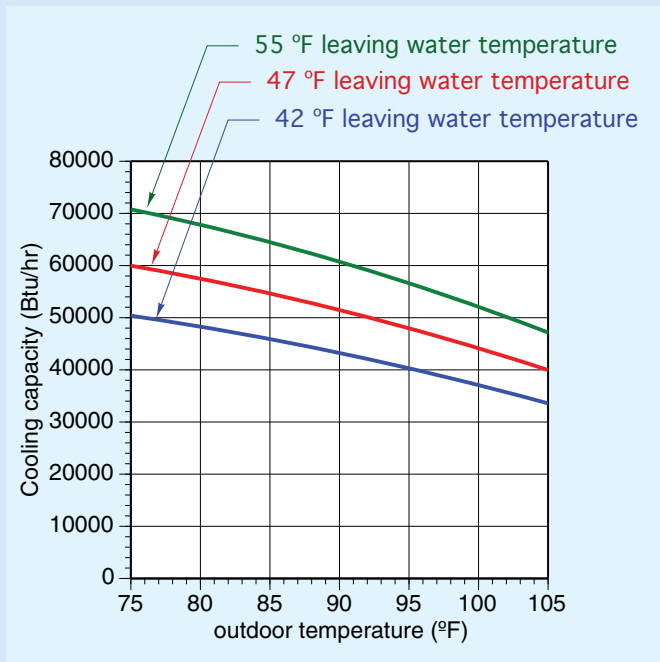
As the water temperature leaving the evaporator increases, all other operating conditions being the same, the cooling capacity and energy efficiency ratio (EER) of the heat pump also increase. Higher capacity increases the rate of chilled-water production. Higher EER reduces the amount of electrical power needed per unit of cooling capacity.

This implies that the higher the chilled-water temperature at which the cooling distribution system can operate and still satisfy to the total cooling load, the better the cooling performance of the heat pump.

Chilled-water distribution systems that manage the sensible portion of the cooling load (e.g., lowering the interior air temperature but not removing moisture from the air) using radiant panels or chilled beams can operate at water temperatures that are substantially higher than systems that manage the latent portion of the cooling load (e.g., removing moisture from the air).

However, sensible cooling alone cannot satisfy the total cooling load requirement, because it does not remove moisture from the interior air. Moisture removal is usually accomplished by circulating chilled water in the temperature range of 40º to 50ºF through the coil of an air handler. The chilled water lowers the surface temperature of the coil well below the dewpoint of the air passing through it. Thus, water vapor in the airstream condenses on the coil. The accumulating condensate eventually drips into a collection pan under the coil and is routed to a suitable drain.

The lower the outdoor air temperature, with all other operating conditions being equal, the higher the cooling capacity and EER of the heat pump. Although there is very little that can be done to control outside air temperature, placing the heat pump in a shaded area and away from surfaces heated by the sun will slightly improve its performance. Operating the heat pump at night, when outdoor temperatures are lower, also improves its cooling performance.

Chilled-Water Piping Practices:

The piping options that are used in hydronic heating systems can also be used for chilled-water distribution. This includes copper, steel, PEX, PEX-AL-PEX and PP-R (polypropylene random).

The crucial difference between piping used for hydronic heating versus cooling is that all chilled-water piping and other piping components must be insulated, and that insulation must be protected against moisture absorption.

This is necessary because the outer surface temperature of piping carrying chilled water is often well below the dewpoint of the interior air surrounding that piping. Without the proper insulation and vapor protection, water vapor in the air will quickly condense on piping surfaces, as seen on the copper piping in Figure 15. Condensate is also likely to form on any uninsulated surfaces of components, such as valves and circulators, as shown in Figure 16.

Figure 15

Source: Greenbuilding advisor.com

Figure 16

Within a few minutes, this condensed water will be dripping off the piping and piping components and can potentially damage interior surfaces and other objects below the piping. Condensation can also lead to conditions that foster mold growth.

There are several types of insulation systems that can be used on chilled-water piping. These include fiberglass insulation with a vapor barrier, cellular glass insulation and elastomeric foam insulation. The latter is more commonly used in smaller systems. It is available in pre-slit lengths that can be easily placed around piping. It is also available in preformed pieces that fit around fittings such as tees, as well as in sheets and strips that can be cut and fit as needed. Figure 17 shows examples of these elastomeric insulation products.

Figure 17
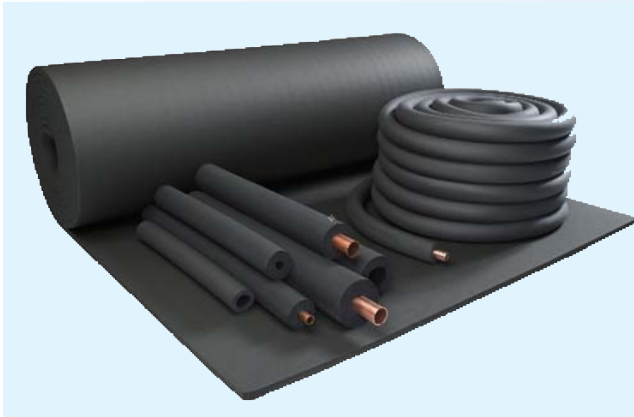
Some elastomeric foam insulations have very low vapor permeability. This eliminates the need for a separate vapor barrier wrapping or coating to prevent moisture absorption, as is required with fiberglass insulation products. However, elastomeric insulation is subject to ultraviolet degradation, and should be coated or wrapped when exposed outside (such as on the piping between an air-to-water heat pump and the building it serves).

It is very important to insulate the piping, fittings and the body of piping components such as valves and heat exchangers. The volutes of any circulators conveying chilled water should also be insulated. However, never insulate the motor portion of circulators or the actuator portion of zone valves.

Figure 18 shows chilled-water piping passing through zone valves. The bodies of the valves are insulated, but the actuators are not. This allows the actuators to remain warm enough that condensate will not form on their internal electrical components.

Figure 18

Figure 19 shows examples of elastomeric foam insulation on chilled-water piping.

Figure 19

Notice that the electrical portion of the two flow switches seen in the foreground are not insulated. This is correct practice. It allows the exposed portion of these devices, which contain internal electrical components, to remain warm enough to prevent condensation.

All piping insulation should be bonded together using an adhesive endorsed by the insulation manufacturer. Any gaps between insulation segments will allow moisture-laden air to enter, and condensation will soon follow. This condensate will accumulate and eventually leak from unsealed joints between insulation pieces.

It is also important to support insulated chilled-water piping so that the insulation does not undergo significant compression due to the forces transferred between the piping and its supports. Figures 20a and 20b show examples of insulated support collars that distribute the loading transferred to a pipe hanger over several square inches of a material that is more rigid than the elastomeric insulation it displaces. Once the support collars are installed, the elastomeric insulation is glued to them. This provides continuity of insulation and vapor protection without excessive compression at support points.
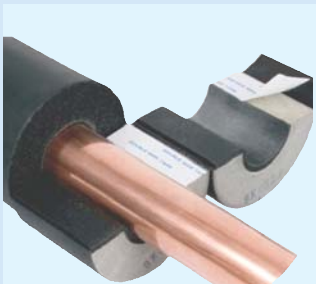
Figure 20a   Figure 20b

Courtesy of ZSi Inc.

### Chilled-Water Terminal Units:

A "terminal unit" is any device that's designed to absorb heat from an interior space and transfer it to a stream of chilled water. There are many types of terminal units now available that are suitable for smaller chilled-water cooling systems. They range from traditional chilled-water air handlers to site-constructed radiant ceiling panels. Some are designed to provide both sensible and latent cooling, while others can only provide sensible cooling, and typically require an "auxiliary" terminal unit for latent cooling.

One of the most common chilled-water terminal units is known as an air handler. It contains a "coil" made of copper tubing and aluminum fins, as well as a blower. Chilled water passes through the copper tubing and cools the attached aluminum fins. The blower forces air through the spaces between these fins and tubes. The air emerges from the downstream side of the coil at a lower temperature and reduced moisture content. Figure 21 shows an example of a smaller horizontal fan-coil. Figure 22 shows its schematic representation and internal construction.
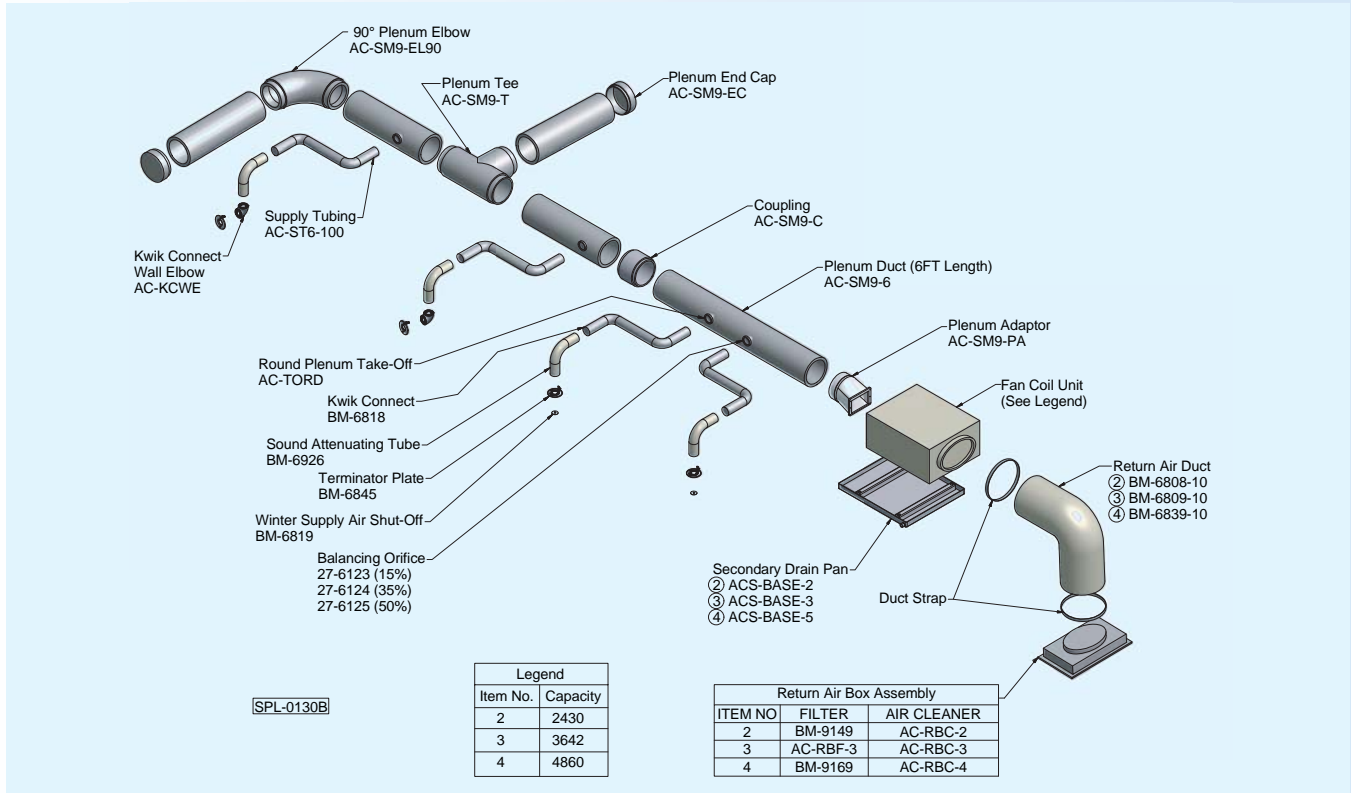
Figure 21

Figure 22
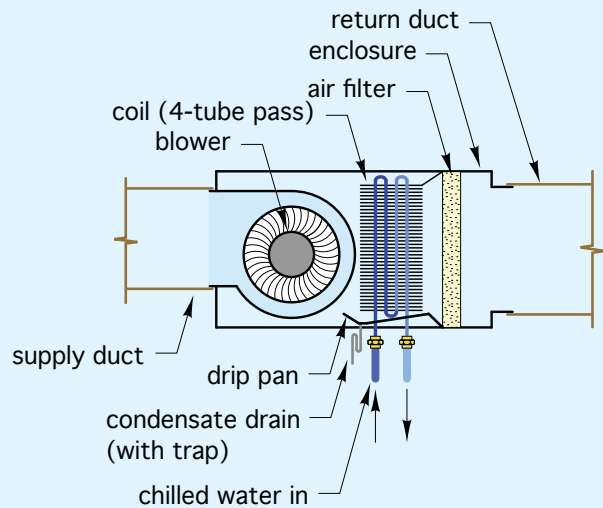
Notice that Figure 22 shows a "drip pan" under the coil. This pan collects water droplets that fall from the coil as the air passing through it is dehumidified. On a humid day, even a small air handler can produce several gallons of condensate. This water must be routed to a suitable drain. The small tube seen near the base of the air handler in Figure 21 is the condensate drain connection.

Air handlers are typically located in mechanical rooms, above suspended ceilings, or in other non-occupied building areas. These spaces provide access to the air handler, but also isolate it from occupied areas.

An air handler is supplied with "return air" from one or more locations in the building. As it passes through the air handler's coil, this air is cooled and dehumidified. The conditioned air passes through the air handler's blower and is discharged to a duct system. The duct system divides into branches to distribute the conditioned air to several interior spaces.

SpacePak offers air handlers that use special blowers capable of generating higher air pressure in the supply ducting. This allows the branches to be small, 2-inch diameter flexible ducts that can easily be routed through the typical framing spaces in wood-framed buildings. Figure 23 shows a general layout for this type of air handler and its ducting system.

Figure 23

90° Plenum Elbow
AC-SM9-EL90

Plenum Tee
AC-SM9-T

Plenum End Cap
AC-SM9-EC

Supply Tubing
AC-ST6-100

Kwik Connect
Wall Elbow
AC-KCWE

Coupling
AC-SM9-C

Plenum Duct (6FT Length)
AC-SM9-6

Plenum Adaptor
AC-SM9-PA

Round Plenum Take-Off
AC-TORD

Kwik Connect
BM-6818

Sound Attenuating Tube
BM-6926

Terminator Plate
BM-6845

Winter Supply Air Shut-Off
BM-6819

Balancing Orifice
27-6123 (15%)
27-6124 (35%)
27-6125 (50%)

Fan Coil Unit
(See Legend)

Return Air Duct
② BM-6808-10
③ BM-6809-10
④ BM-6839-10

Secondary Drain Pan
② ACS-BASE-2
③ ACS-BASE-3
④ ACS-BASE-5

Duct Strap

SPL-0130B

Legend	
Item No.	Capacity
2	2430
3	3642
4	4860

Return Air Box Assembly		
ITEM NO	FILTER	AIR CLEANER
2	BM-9149	AC-RBC-2
3	AC-RBF-3	AC-RBC-3
4	BM-9169	AC-RBC-4

Each branch duct ends at an inconspicuous room terminator, which can be located in ceilings, walls or floors. As a guideline, there are typically seven of the 2-inch size branch ducts used per ton (12,000 Btu/hr) of cooling capacity supplied by the air handler.

Some small air handlers are also capable of independently controlling multiple zones of heating or cooling. An example is shown in Figure 24.

Figure 24

This air handler has a high-efficiency blower motor which can run at variable speeds depending on the temperature of the entering air. It also has air inlet dampers that can be connected to two separate return-air locations in the building, allowing for two independently controlled zones. This unit also provides a connection for ventilation air and contains a drip pan. It is fully compatible with chilled-water cooling.

There are also "ductless" terminal units that can be used for chilled-water cooling as well as hydronic heating. One example is the high wall cassette shown in Figure 25.
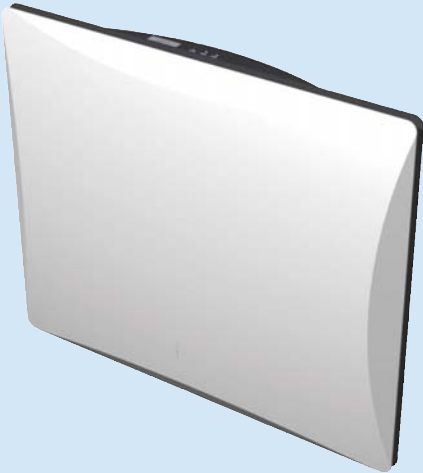
Figure 25

Source: USDOE

This high wall cassette uses a very quiet fan to move air across its chilled-water coil. A small motorized damper in the air discharge path slowly changes it angle to spread the conditioned air throughout the room.

Another example of a ductless terminal unit is the wall convector shown in Figure 26.

Figure 26

This low-profile unit can be individually controlled, and thus can provide room-by-room zoning control in both heating and chilled-water cooling modes.

Both of these wall-mounted terminal units have condensate pans that capture water dripping from their coil. A flexible tube then carries this water to a suitable drain. In some cases,

the condensed water is routed into the building's drainage plumbing system. When this method is used, it's imperative to create a P-trap between the drainage tube and plumbing drainage stack to ensure that sewer gases cannot migrate backward into the terminal unit.

The piping that carries chilled water to and from these terminal units could be rigid metal tubing, polypropylene tubing or flexible PEX tubing. The size of the tubing depends on the cooling capacity of the terminal unit, as well as the length of tubing required between the beginning of the branch circuit and the terminal unit. The smallest terminal units may be able to use tube sizes as small as ½-inch. Larger terminal units, or those with long branch circuits may require larger tubing in sizes of ¾-inch or 1-inch.

Designers should use standard piping design practices to evaluate the flow and head loss requirements of the branch circuits serving each terminal unit, and then select an appropriate tube size.

A suggested temperature rise across the cooling coil in a terminal unit is 10ºF. This temperature drop implies a chilled-water flow rate of 2.4 gallons per minute (gpm) per ton (12,000 Btu/hr) of cooling capacity.

One of the previously cited benefits of chilled-water cooling was the ability to easily zone the system. The terminal units discussed thus far can all be incorporated into a zoned chilled-water distribution system. One concept for such a system is shown in Figure 27.

Figure 27
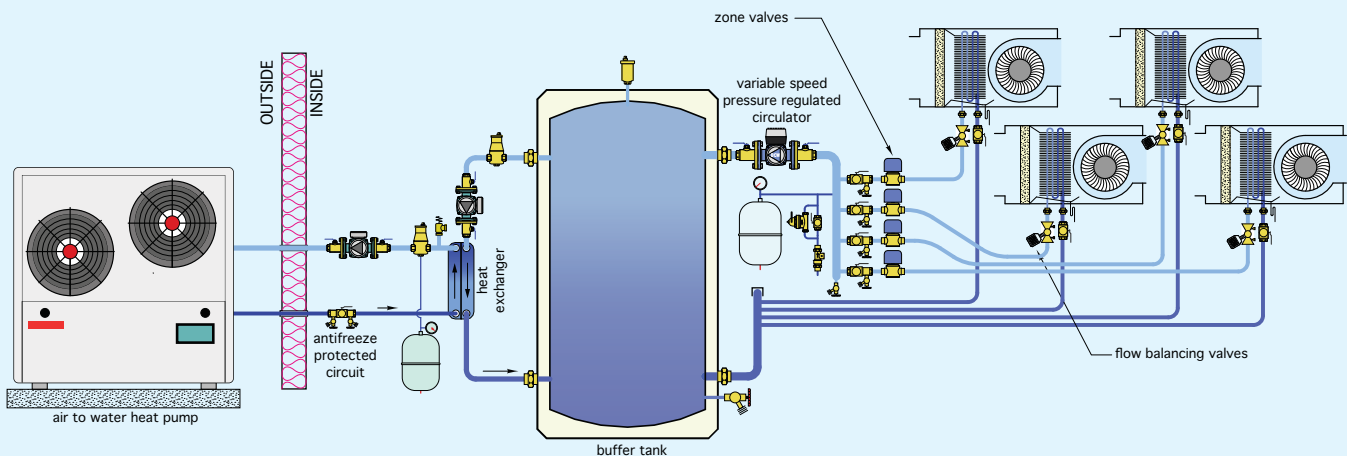
In this system, an air-to-water heat pump is used as the cooling source. It chills an antifreeze solution that circulates between the heat pump and a stainless steel heat exchanger located within the mechanical room. This antifreeze solution protects the heat pump and exterior piping from freezing during winter. The chilled antifreeze absorbs heat from water that is circulated from the upper portion of the buffer tank, through the heat exchanger, and back into the lower portion of the tank. The buffer tank allows the cooling capacity of the heat pump to be different from the current cooling needs of the chilled-water distribution system. This prevents the heat pump from short cycling during partial load conditions.

Each chilled-water terminal unit operates independently to meet the cooling requirements of its interior space. Flow through each zone circuit is controlled by a zone valve. A variable-speed circulator with a high-efficiency motor adjusts the flow rate through the distribution system based on the number of zones that are operating. This type of circulator minimizes electrical energy use, which in turn reduces the cooling load on the system.

Systems based on the concepts shown in Figure 27 could supply fewer zones or more zones. They can also be configured to supply heating through the same terminal units during colder weather. In this mode, the heat pump operates in its heat mode and adds heat to the water in the buffer tank.

Radiant Cooling:
Another approach to chilled-water cooling uses an interior room surface to directly absorb heat from the space and its occupants. This approach is commonly called radiant cooling.

Unlike terminal units that allow water vapor to condense within them, and thus provide both sensible and latent cooling, radiant-cooling panels must operate without condensation. As such, they can only provide sensible cooling to the interior spaces they serve. Latent cooling (e.g., moisture removal from interior air) is usually provided by a separate chilled-water air handler, or a dedicated outdoor air system (DOAS) which also provides ventilation airflow.

The 8- to 12-foot high ceilings in most residential and light-commercial buildings are ideal for radiant cooling. Ceilings have an excellent radiant "view factor" of the surfaces and occupants below them. A typical cooled ceiling provides approximately 60% of its cooling effect by absorbing radiant heat emitted by objects and occupants in the room below. The remaining heat absorption is accomplished by gentle convective air currents.

Radiant cooling uses significantly less electrical distribution energy compared to systems that deliver all the cooling capacity using forced air. This is again based on the ability of water to absorb and convey heat using a tiny fraction of the flow rate required by an equivalent forced-air system. Radiant ceilings can also provide excellent heating. They can be supplied with warm water produced by the same air-to-water heat pump that provides chilled water for cooling.

The construction details shown in Figure 28 provide a high-performance radiant ceiling panel with low thermal mass. The latter characteristic allows the panel to respond quickly to changes in load or water temperature. Figures 29a through 29c show portions of how this ceiling panel is constructed.
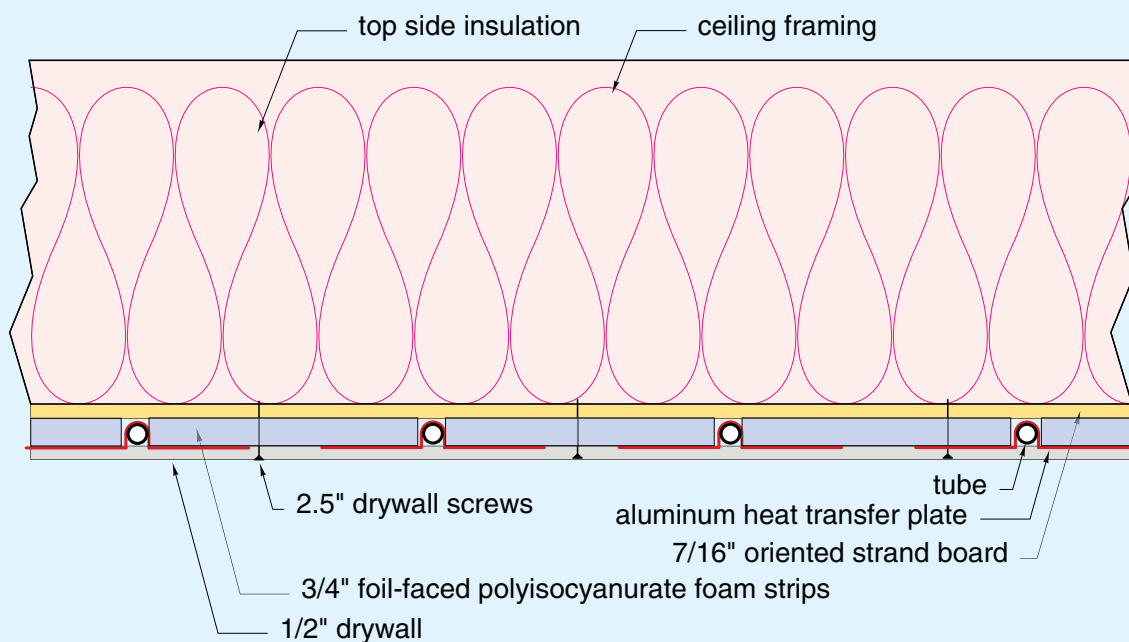
Figure 28

top side insulation   ceiling framing
2.5" drywall screws
tube
aluminum heat transfer plate
7/16" oriented strand board
3/4" foil-faced polyisocyanurate foam strips
1/2" drywall

Figure 29a

Figure 29b

Figure 29c

The rate of heat absorption for the radiant ceiling panel shown in Figure 28 can be calculated using Formula 5.

Formula 5

$$q = 1.48\,(T_R - T_C)^{1.1}$$

where:
q = rate of heat absorption (Btu/hr/ft²)
T_R = average of room air and room mean radiant temperature (ºF)
T_C = average lower surface temperature of ceiling (ºF)
1.1 = an exponent (not a multiplier)

Suppose the room's operative temperature (e.g., the average of its air temperature and mean radiant temperature) was 75ºF, and the average temperature of the ceiling surface was 70ºF. This ceiling could absorb about:

$$q = 1.48\,(T_R - T_C)^{1.1} = 1.48(75-70)^{1.1} = 8.7\,\frac{Btu}{hr \cdot ft^2}$$

Lowering the ceiling's average surface temperature to 65ºF would increase heat absorption to about 18.6 Btu/hr/ft².

The temperature of the water within the radiant panel is slightly lower than the ceiling's surface temperature. For the panel in Figure 26, the difference between the average ceiling surface temperature and the average water temperature in the circuit can be estimated using Formula 6.

Formula 6

$$\Delta T_{SW} = 0.426(q)$$

where:
ΔT_{SW} = the difference between average water temperature in the panel and average ceiling surface temperature (ºF)
q = rate of heat absorption (Btu/hr/ft²)

Thus, if the rate of heat absorption is 8.7 Btu/hr/ft², as was previously calculated, the difference between the average water temperature in the panel and ceiling surface temperature would be:

$$\Delta T_{SW} = 0.426(q) = 0.426(7.7) = 4ºF$$

The surface temperature of radiant-cooling panels must be maintained high enough to prevent condensation. If the temperature of the surface, or the components within the radiant panel, fall below the room's current dewpoint temperature, water vapor in the air will condense on (or within) the panel. This would quickly create stains on the panel, and eventually allow water to drip from the panel into the room below. Thus, it is imperative to constantly monitor the room's dewpoint temperature and provide controls that

maintain the chilled-water supply temperature to the radiant panel at least 3ºF above that dewpoint.

The required temperature control can be achieved using a 3-way motorized mixing valve that is operated by a controller that measures and responds to the dewpoint temperature of an interior space. Figure 30 shows how this valve and controller would be used along with chilled-water piping mains and a manifold station supplying several radiant panel circuits.

The component arrangement for the radiant panel in Figure 30 is identical to that used to regulate warm water flow through the panel for heating. The only difference is the control logic used to operate the 3-way motorized mixing valve. Thus, with the proper controller, the radiant panel can provide both heating and sensible cooling.

In systems that use radiant panels for sensible cooling, the latent cooling load is usually assigned to a chilled-water air handler. In many cases, this air handler is also configured to provide ventilation air to the space, as shown in Figure 31.
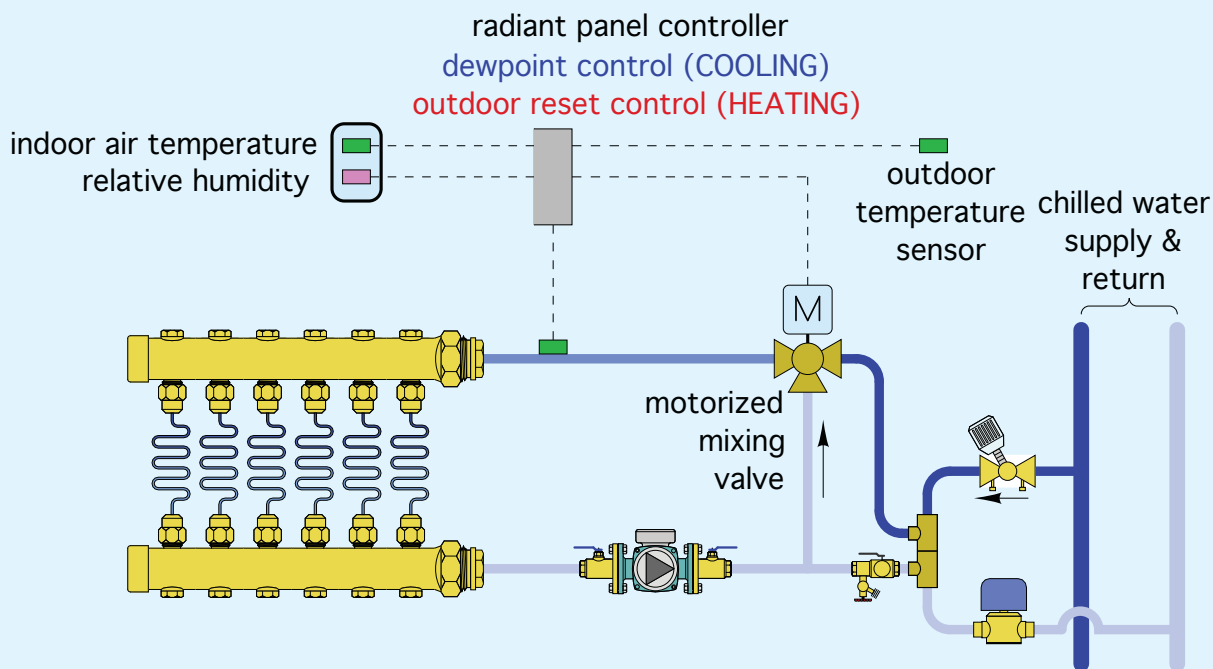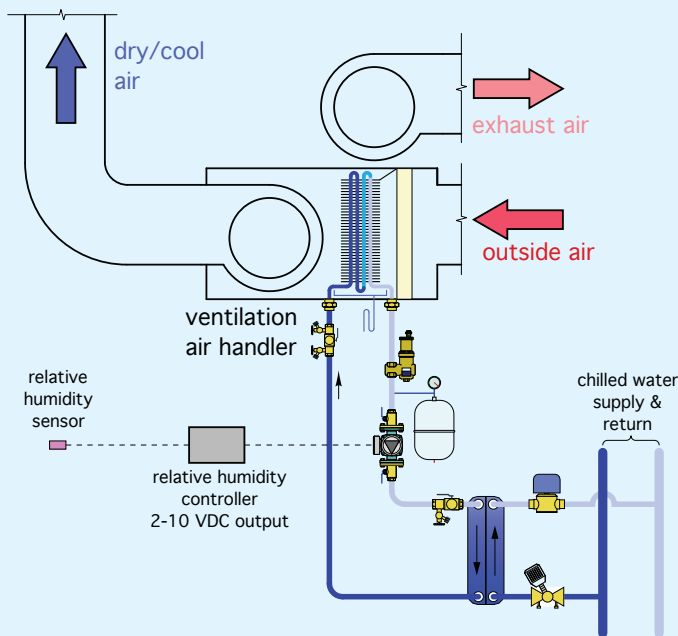
Figure 30

Figure 31

The circuit supplying the air handler's coil is set up to operate with an antifreeze solution to protect it during winter when incoming ventilation air may be below freezing. The antifreeze solution circulates between the air handler's coil and the stainless steel plate heat exchanger. During cooling operation, the antifreeze is cooled by chilled water passing through the other side of the heat exchanger.

In larger residential or light-commercial buildings that require more than 4 or 5 tons of cooling, it's possible to use multiple air-to-water heat pumps as staged chillers.

On mild days, only one chiller needs to operate, but on hot, humid days, automatic controls turn on additional chillers to create the necessary cooling capacity. Figure 32 shows an example of multiple air-to-water heat pumps that can be used as staged chillers, or as staged heat sources during the heating season.

Figure 32

Figure 33 shows how several of the subsystems just described can be combined to create a complete chilled-water heating/cooling/ventilation system.

Figure 33
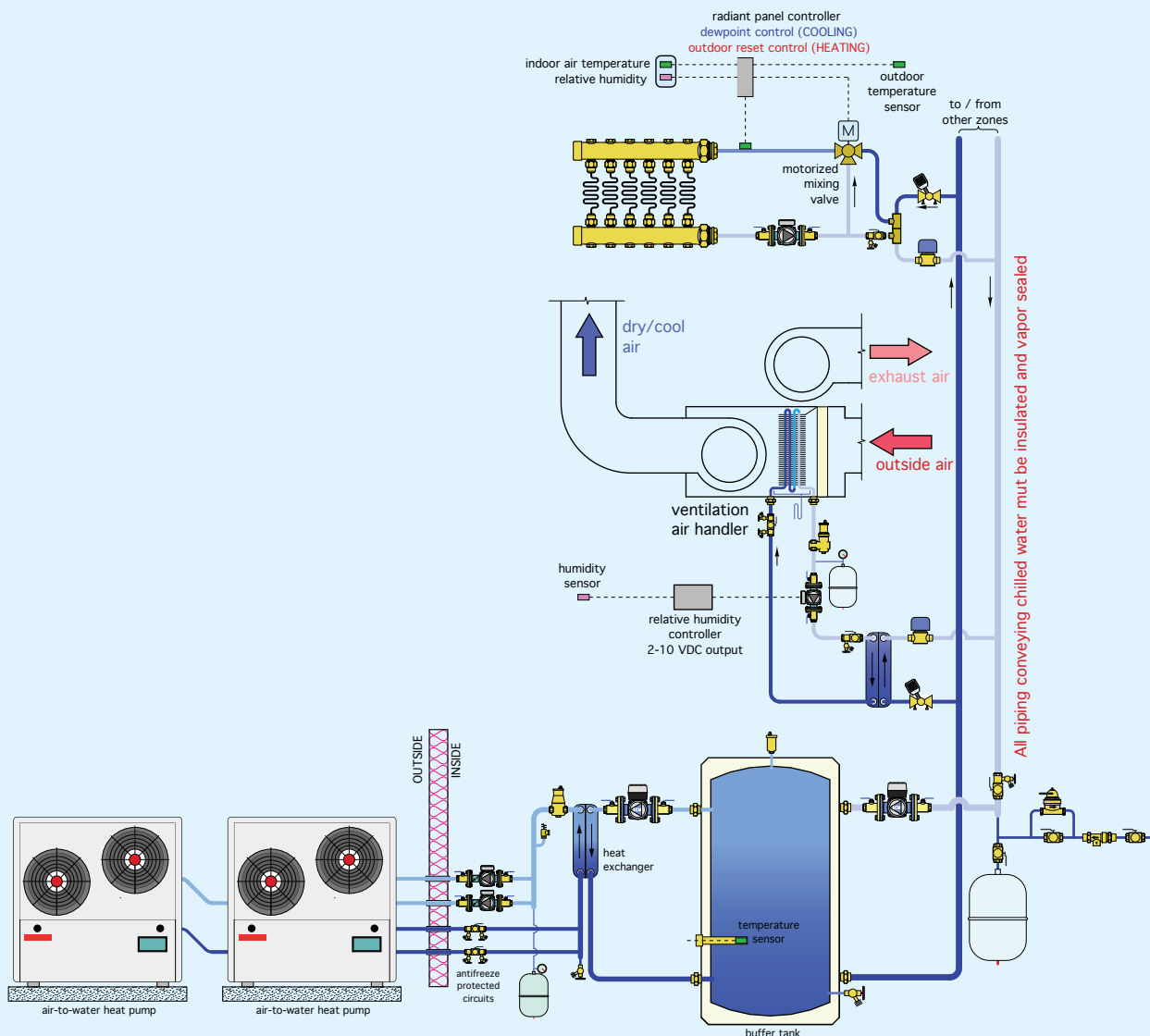
This system uses radiant panels for sensible cooling and an air handler for latent cooling and conveyance of ventilation air. The same radiant panel is used for heating during cold weather. Two air-to-water heat pumps serve as chillers during the cooling season and heat sources during cold weather. When operating in cooling mode, both chillers cool the water in the buffer tank. This water is then supplied by a variable-speed circulator to the radiant-panel cooling subsystem and the air handler.

A motorized mixing valve driven by a dewpoint controller maintains the chilled-water temperature to the radiant panels at 3ºF above the current dewpoint temperature of the room air.

A variable-speed circulator is used to control the flow rate of chilled antifreeze solution through the coil of the air handler. This flow is increased or decreased in response to the relative humidity setpoint of the interior space.

Chilled Beams:

Although relatively new in North America, chilled beams have been used for cooling in European buildings for more than four decades. *They are designed to absorb only sensible heat from air passing through them,* and must therefore be supplemented by an air-handling system that provides latent cooling.

Chilled beams are classified as "active" or "passive."

Active chilled beams have ventilation air ducted to them. This air has been preconditioned in both temperature and moisture content before it is sent to the chilled beam. This preconditioning allows the air to absorb moisture from the space, and thus manage the latent portion of the cooling load.

The preconditioned "dry" air enters the chilled beam and passes through nozzles that increase airflow velocity and decrease local air pressure. The reduced pressure induces airflow through the chilled-water coil, where the temperature and moisture content of the air is reduced. The moisture reduction results from the room air mixing with the dry ventilation air. No condensation occurs during this process. The conditioned air is then gently reintroduced to the room through slots near the outer edges of the chilled beam, as shown in Figure 34b.

A typical 6-foot-long active chilled beam, when supplied with 58ºF chilled water and 40 CFM of ventilation air, will provide approximately 3,600 Btu/hr of sensible cooling at very low sound levels of about 25 decibels.

Figure 35 shows a typical chilled beam mounted in a suspended ceiling.

Figure 34a

Figure 34b

chilled beam   air nozzles
dry, ventilation air intake
chilled water coil
ceiling   ceiling
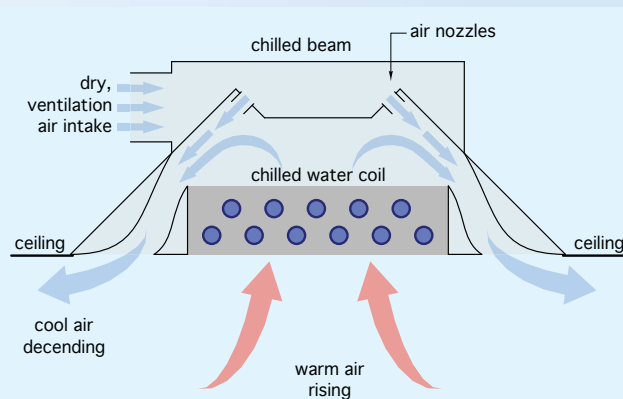cool air decending
warm air rising

Figure 35

Active chilled beams significantly reduce the size of ducting required in the building. In dry climates, the ducting is primarily sized for the peak ventilation airflow. In climates with higher humidity, the airflow rate is typically based on the latent cooling load, and is usually higher than the airflow required for ventilation. Reduced airflow means that smaller ducting can be used and can lower power blowers. This can result in operating costs that are up to 50% lower than those of variable air volume (VAV) systems.

Passive chilled beams do not have ventilation airflow. They are used to supplement heating or sensible cooling capacity in spaces where sufficient ventilation air is introduced through active chilled beams or other means.

Summary

Although hydronic technology is better known for unsurpassed heating comfort, it is now possible, and practical, to employ hydronics technology for cooling residential and light-commercial buildings. Small-scale chilled-water cooling delivers many benefits, such as zoning, low-distribution energy use, longevity and ability to integrate with thermal storage. Many systems that supply chilled-water cooling can be easily configured to also supply hydronic heating, as well as ventilation, and thus provide a total solution for comfort needs. SpacePak offers a wide variety of high-performance hardware that can be used to build these types of systems.

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