WHITEPAPER

Introduction to Water Source Heat Pump Systems

JMP Equipment Company

Water source heat pumps (WSHP) have become the go-to heating and cooling solution for a wide range of commercial-sized buildings—and with good reason. Few engineered HVAC systems offer better efficiency, flexibility and lifecycle costs; and almost none are as simple to design, install and maintain. This whitepaper provides a high level overview of the advantages and basic operation of WSHP systems for engineers, contractors and commercial owners who are considering this technology.

The primary function of the mechanical components in a WSHP system is to store and transport BTUs to where they are needed and remove them from where they are not. For that reason, it is helpful to think of these systems as a battery rather than a means through which heating and cooling is produced.

A commercial WSHP system typically incorporates multiple WSHP units, each serving a specific, individually controlled zone. These units operate similarly to residential air source heat pumps (ASHP) which reject and absorb heat from the outside air. However, instead of exchanging BTUs with the outside air, WSHPs use a common water pipe to store and transport BTUs. All the heat pumps are tied to this central "water" or "hydronic" loop, which serves as the BTU battery. The heat pumps add and remove heat to and from the water loop as needed to keep their individual zones satisfied. Because water conducts energy more effectively than air, WSHPs are much more efficient than ASHPs.

Most of the time in commercial WSHP systems, the hydronic loop is connected to a cooling tower, which rejects excess heat from the loop to the outdoor air; the loop may also be connected to a boiler to add heat to the loop when it is running short on BTUs.

Back in the building spaces, heating and cooling occurs exactly as required because the central loop is kept within a specific broadband temperature range. Any time the water loop temperature is at risk of slipping above or below range, either the cooling tower or boiler will activate to keep it within range.

This brings us to one of the most appealing aspects of WSHP systems: the ability to provide simultaneous heating and cooling. This is different from most commercial hydronic systems, which are typically designed as 4-pipe systems with separate supply/return piping for both heating and cooling. These systems utilize a central chiller for cooling and a central boiler for heating. They also utilize a central switch to universally change the system from heating to cooling mode and vice versa.

WSHP systems require no such universal switch because they can and frequently do provide simultaneously heating and cooling to buildings throughout much of the year, depending on the climate and the heat loss characteristics of the building they serve. This is due to the fact that in the winter the interior spaces of buildings typically stay much warmer than the perimeter zones and may even require cooling while other parts of the building require heat. A WSHP system makes it possible to exchange BTUs between these zones without having to create or reject heat.

Primary Advantages

WSHP systems offer several advantages that make them appealing to building owners and occupants. These are discussed throughout this paper in detail, but are summarized below for brief introduction:

Installation and Operational Flexibility. Individual WSHP units can be placed above drop ceilings, in mechanical rooms or even in closets within the zones they are serving. This significantly reduces the amount of ductwork required for a given project. Each WSHP unit is individually controlled for the zone it serves, although there is also an option that allows for global control of units via a central Building Automation System (BAS).

Space Efficiency. Compared to systems that rely on traditional central heating and cooling plants with costly primary and secondary pump loops, lengthy duct runs, and additional air handling equipment, WSHP systems utilize a single, relatively small diameter pipe for the entire water loop and no supply or return air duct between zones. (Note: A single 2-inch water pipe can carry the same amount of cooling as a 24-inch air duct!) This not only saves vast amounts of space, it is more efficient. The central water loop can also serve other types of equipment such as domestic hot water heat pumps, dedicated outside air units, and even water-cooled variable refrigerant (VRF) units. This makes WSHP systems particularly adaptable to expansion.

Low lifecycle costs. Owners of WSHP systems will typically be rewarded with low lifecycle costs. The lifespan of WSHPs is comparable to that of packaged chillers while the installed costs are favorably lower, approximately the same as a packaged rooftop unit. Since WSHP systems are designed with individual zone control, if one WSHP unit goes down, only that zone will be affected. That's far less impactful than the loss of a central chiller, which would result in multi-zone failure and major replacement or repair costs.

High Efficiency. WSHPs are among the most energy-efficient HVAC appliances available to commercial buildings. This is due to the efficient heat transfer of water, as well as the BTU storage capability of the hydronic loop. As a point of reference, a 2,000 gallon water loop with a 50°F to 90°F temperature range can store over 650,000 BTUs. The units are so efficient that ASHRAE actually holds them to a higher efficiency standard (13.0 EER for cooling and 3.7 COP for heating) than it does on similarly sized air-cooled equipment and VRF systems.

Environmentally Friendly. Not only do WSHPs operate without the combustion of fossil fuels, they use a scant amount of refrigerant compared to other HVAC appliances. A 2-ton WSHP unit only contains about 43 ounces of refrigerant. This helps buildings meet ASHRAE's Refrigerant Code Standards 15 and 34 which address refrigerant concentration limits for a given area. Furthermore, the refrigeration circuit in each unit is self-contained, so if a leak occurs it will not impact other zones or equipment.

When to Consider WSHPs

Water source heat pump (WSHP) systems can be successfully and advantageously applied in a wide variety of commercial, institutional and multi-unit residential buildings. The commonality that makes any of these potentially suitable for WSHP design is the need for simultaneous heating and cooling with individualized zone control. But WSHPs can be useful in meeting other requirements as well.

Multi-Story, Multi-Tenant Applications. WSHPs are an excellent choice for multi-story, multi-tenant buildings for a number of reasons—some of which may you. Obviously, most tenants want total thermostatic control in their living environments, while landlords or property owners want to be able to charge tenants for their individual energy use. Many governmental facilities and military have similar needs. WSHPs make individual zone control and unit metering easy.

Figure 1. A stacked WSHP installation, typical of multi-unit, vertical chase application.

If the building happens to be multi-storied, as many hotels and multifamily residences are, WSHPs also facilitate design layout and installation because they be installed in a stacked fashion within a vertical chase. These tall, thin units are not only small in footprint, they are also easy to pipe because the piping is pre-measured and pre-fabricated at the factory. The supply and return piping in these applications can be configured in a myriad of ways to accommodate the space layout and zone requirements. Plus, vertical stack installations can significantly reduce the amount of required piping, especially if the space layouts are identical on each floor. The cabinet doors can be painted to blend into the wall surface of the space, or the units may be tucked into a small closet. (Figure 1)

Facilities with Strict Refrigerant Limitations. Refrigerant leaks can be harmful to building occupants, not to mention the environment. Institutional facilities, in particular, are subject to increasingly strict limitations on the amount of refrigerant in HVAC appliances due to environmental and health risks. This trend favors WSHPs, since they use only a small amount of refrigerant, all of which is contained within the unit. If a refrigerant leak occurs, it will amount to ounces rather than pounds. This is not the case with other types of appliances used in multi-zone applications, e.g. variable refrigerant (VRF) systems, which do share refrigerant lines between units. WSHPs also help facilities meet the latest ASHRAE 15 guidelines limiting the amount of refrigerant in a closed environments.

When Peace and Quiet Are a Priority. WSHPs are remarkably quiet thanks to new compressor technology and acoustical isolation techniques. This makes them a good choice for learning and work environments. They can be applied to a single zone without introducing any more noise than a fan coil unit. Chillers and high-speed, high static centrifugal fans used in centralized HVAC systems generate a lot of noise and vibration that can be transmitted to occupied spaces and may require costly attenuation measures.

Renovation and Retrofits. WSHP systems provide a lot of design flexibility, making them an excellent choice in building retrofits and renovations. Case-in-point is the newly renovated ASHRAE Global Headquarters in

Peachtree Corners, Georgia, where WSHPs play an important role in helping the building achieve net-zero-energy status. (See Side Bar)

Basic Operation of WSHPs

WSHPs operate similarly to traditional air source heat pumps (ASHPs) in that they transfer heat rather than create it from a combustible fuel. Both incorporate a refrigeration cycle to facilitate heat transfer and both include a valve to reverse the refrigeration cycle, depending on whether the unit is in heating or cooling mode. The primary distinction between WSHPs and ASHPs is that WSHPs absorb and extract heat from a water loop, while ASHPs absorb and extract heat from the outdoor air.

In commercial applications, multiple WSHPs are typically connected to the common water loop. This is maintained within an operating temperature range of 60°F to 90°F. When more zones need heating than cooling, the loop temperature drops (approaching 60°F) and a boiler may be activated to keep the loop within its operating range. When more zones need cooling than heating, the loop temperature rises as more heat is extracted from the zones. As the water loop approaches the high limit of its operating range, a cooling tower may be activated to reject the surplus heat.

Because buildings with multiple zones encounter peak heating and cooling demands at different times during the day, individual heat pumps usually have capacity to spare. So boiler or chiller operation may only be necessary during peak heating and cooling seasons.

ASHRAE Chooses Water Source Heat Pumps for Global Headquarters

Water source heat pumps (WSHPs) played an important role in the 2020-2021 redesign of the ASHRAE Global Headquarters in Peachtree Corners, Georgia. The goal for the redesign was to achieve a fully net-zero-energy building, a milestone that was officially achieved in Fall of 2021. The clever application of WSHPs at the Headquarters demonstrates the ultimate flexibility of WSHPs in the most challenging of renovations.

Six WSHPs were selected to provide conditioning of the facility basement and upper level atrium. The units are supplied with chilled water from return chilled water from radiant ceiling panels used for heating and cooling. This application worked because of the fact that WSHPs function with higher supply water temperatures than other air conditioning equipment. The WSHPs are supplied with air from dedicated outdoor air equipment located on the building rooftop. The WSHPs in the basement were chosen to save energy in a space that is primarily used for storage while the ones serving the Atrium were chosen due to the lack of ceiling in that space.

ASHRAE applied energy meters to the heat pumps and other equipment used throughout the 66,700 sq ft building. Other sustainable building strategies included a 332kW photovoltaic (PV) system, radiant ceiling panels, daylighting and more.

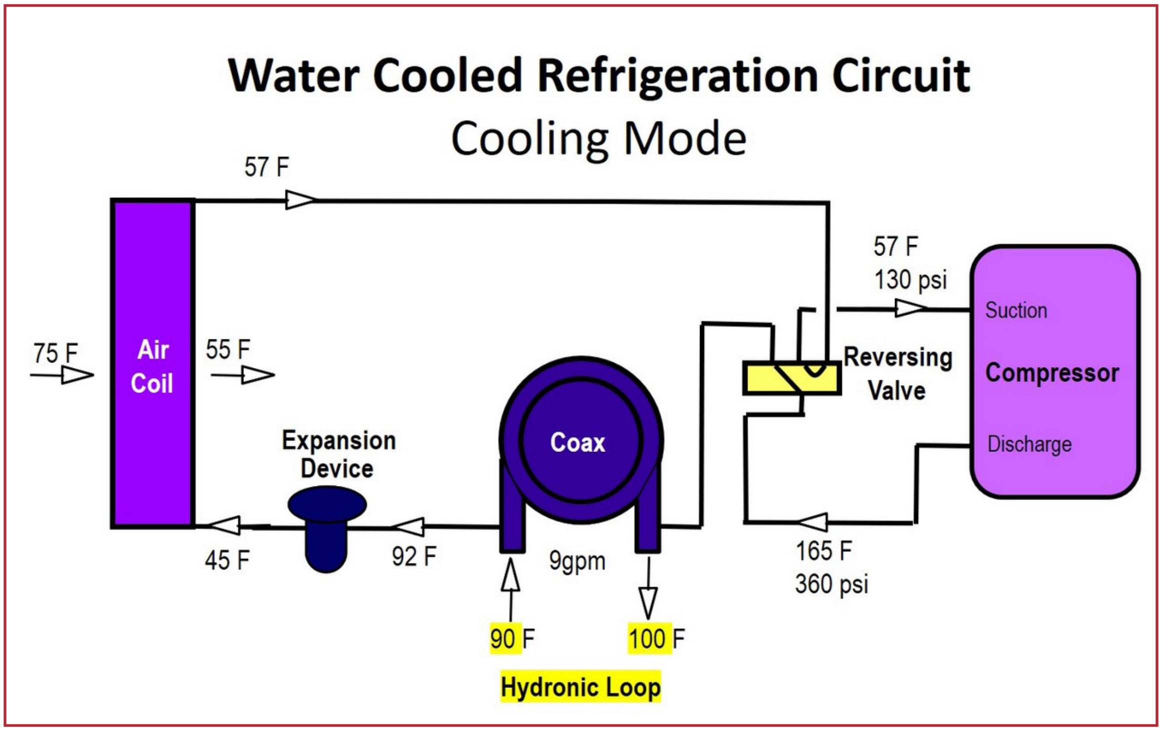

Figure 2. In cooling mode this heat exchanger acts as the condenser while the refrigerant-to-air heat exchanger acts as an evaporator.

Refrigeration Cycle

Like all cooling appliances, WSHPs incorporate a refrigeration cycle. Each WSHP includes two heat exchangers, a refrigerant-to-water heat exchanger and a refrigerant-to-air heat exchanger. The water side of the refrigerant-to-water heat exchanger is fed from the central hydronic loop.

When the WSHP is operating in cooling mode, heat is extracted from the hot return (building) air in the refrigerant-to-air coil through evaporation of the refrigerant. Meanwhile, hot gas from the compressor discharger is directed into the refrigerant-to-water heat exchanger where the hot gas condenses into liquid, giving up its heat to the colder loop water as it passes through the heat exchanger. Liquid refrigerant then passes through a metering device situated between the heat exchanger and the refrigerant-to-air heat exchanger (coil) where it evaporates, resulting in a drop in temperature on the air side. This cooler air is then pushed into the space by a blower. (Figure 2)

In heating mode, this process is simply reversed by way of a reversing valve that sits between the compressor and the refrigerant-to-water heat exchanger.

The refrigeration cycle may sound complex to those who are unfamiliar with mechanical heating and cooling, but it is a process included in virtually all cooling appliances, from refrigerators to chillers. So in this respect, WSHPs are no more complex than any other heating and cooling equipment. It is the water loop design—the inherent BTU battery—that makes WSHP systems more simple to design, operate, and, for that matter, understand.

Many WSHP systems provide simultaneous heating and cooling throughout most of the year. This is when a WSHP is at its most efficient, recovering and redistributing heating and cooling without the help of a chiller or boiler. It is this "give and take" of BTUs between the building zones and the water loop that makes it possible to keep the water loop between 60°F and 90°F most of the time. It is a lot easier to heat a building in the winter by extracting BTUs from 70°F water than from 20°F outdoor air. That's less work (refrigeration cycling) that the heat pump has to do!

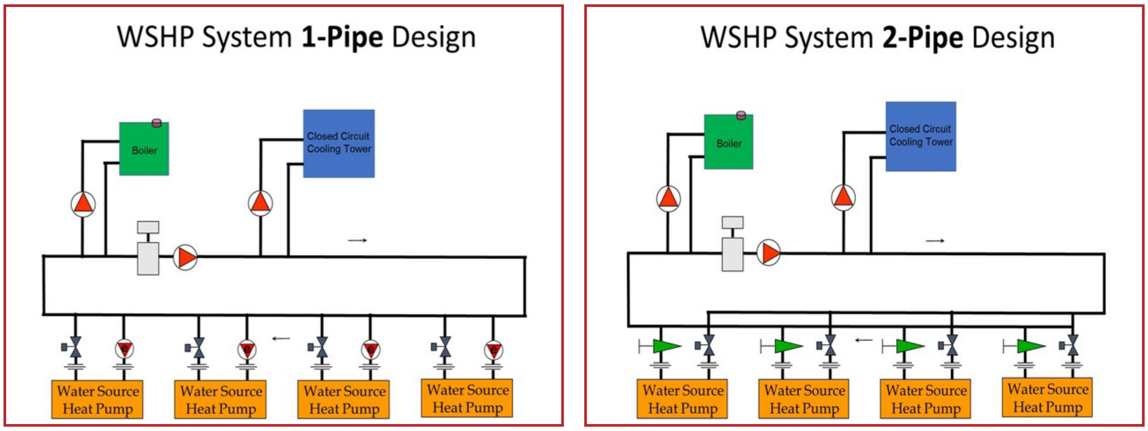

Figure 3

WSHP System Piping Design

One of the most appealing aspects of WSHPs in commercial applications is the overall simplification of piping. After all, you can eliminate the need for chilled, hot and condenser water piping. So instead of choosing between a 2- or 4-pipe system, you have the option of a 1- or 2-pipe system. But what are the differences in 1 and 2-pipe layouts and when might you apply one over the other?

Figure 3 shows two side-by-side images of a 1-pipe and a 2-pipe WSHP system.

1-Pipe System. Notice that in the WSHP 1-Pipe System Design, each WSHP has its own dedicated circulator pump to pump water from the loop and through the unit. These circulator pumps operate independently of the central loop pump, providing the exact flow and head needed to satisfy the requirements of each respective zone, thus eliminating the need for individual control and balancing valves. This arrangement can save pump energy because (1) the circulator pump can be variable speed and turned off during periods of no demand, and (2) the system loop pump does not have to overcome the pressure drop of multiple control and balancing valves.

Each pump is piped in a primary/secondary configuration, but without the need for any special valves or fittings. When the circulator is turned off there is no flow through the unit. The circulator is controlled from the individual WSHP unit and is internally mounted at the factory, saving a lot of time and material at installation.

The return water from each unit in the 1-pipe system goes directly back into the supply loop. In other words, there is no separate return loop. Each heat pump sees a different supply side temperature, as the water will become increasingly warmer (or colder) as it reaches the last heat pump. This must be considered when sizing individual WSHPs in a 1-pipe system. You may also need multiple single pipe loops to control the WSHPs supply temperature depending on the building layout.

2-Pipe Systems. Unlike 1-pipe systems, 2-pipe systems do have separate return and supply piping. This way all the WSHPs see the same supply water temperature since return water doesn't mix with supply. No individual circulator pumps are needed because the entire system is pumped by the central loop pump. However, each WSHP will need to be balanced to make sure it receives the correct amount of flow.

To meet ASHRAE 90.1-2013 standard in a 2-pipe system, a two-position automatic valve must be installed on each unit and interlocked to shut off flow when the compressor is off. We recommend these valves be mounted, wired and set by the WSHP manufacturer to protect the compressors.

2-pipe systems can be either direct or reverse return.

Which Piping Design is Right for You?

While 1-pipe WSHP systems are not well-suited for high rise buildings, they can be advantageous in many schools, office and governmental building layouts and should be considered as a way to reduce installation cost. However, keep in mind that that a 1-pipe system will not reap the full benefit of system diversity. Plus, all of the units in a 1-pipe system must be sized based on the assumption that all are either in heating or cooling mode at the same time. In these cases, the performance of the units near the end of the loop can be impacted because of higher/lower water temperatures. Also, morning start-up in a system with nighttime setback can be tricky with a 1-pipe system.

2-pipe systems work well in any type of building layout. They are simple to design and provide uniformly consistent entering water temperature to all units at all times. A 2-pipe system also provides efficient energy recovery, which can be a benefit in buildings with an interior core that requires year-round cooling and a perimeter zone where heating is required in the winter.

System Comparison

1-Pipe	2-Pipe
Does not require unit balancing if provided with factory mounted variable speed circulator	Utilizes centralized pumping
Lower first cost, due to reduced piping	Units have same entering water temperature
Will not work for all building types	System is less complicated to design
Doesn't take advantage of system diversity	Provides efficient energy recovery and operation in all building types

Geothermal WSHP Systems for Ultimate Efficiency and Longevity

Commercial WSHP systems don't necessarily have to rely on boilers and cooling towers to add or remove heat from the building loop when it surpasses its operating temperature range. They can actually use the earth or a nearby water source (e.g. a pond) instead. In these cases, the WSHP system transfers heat directly to or from the earth or water source. In the HVAC world, these systems are typically referred to as "geothermal" or "ground source" heat pumps. If the building location allows for this approach, a geothermal system is the most efficient of all WSHP systems.

Efficient and Environmentally Friendly

Geothermal heat pumps circulate water through a sealed underground piping loop where it is naturally warmed (or cooled) by the earth. Geothermal systems typically have the lowest operating cost of any WSHP system. That's because the earth maintains fairly stable ground temperatures. In Greensboro, North Carolina, for example, ground temperatures stay at approximately 62°F year-round at a well depth of 30 to 60 ft, regardless of whether the outdoor air temperature is 5°F or 100°F. It is a lot more efficient to extract heat from 62°F soil than 5°F air; or to reject heat into 62°F ground than 100°F air. (Figure 4)

Geothermal systems may even eliminate the need for a cooling tower and/or boiler, or at the very least, reduce their required capacity. They are also an ideal strategy for those looking to build a carbon-free HVAC system or facility, since (like all WSHPs) they do not rely combustible fuel and may allow an owner to forego a fuel-fired boiler. So it is no surprise that geothermal systems are frequently used are in green building projects.

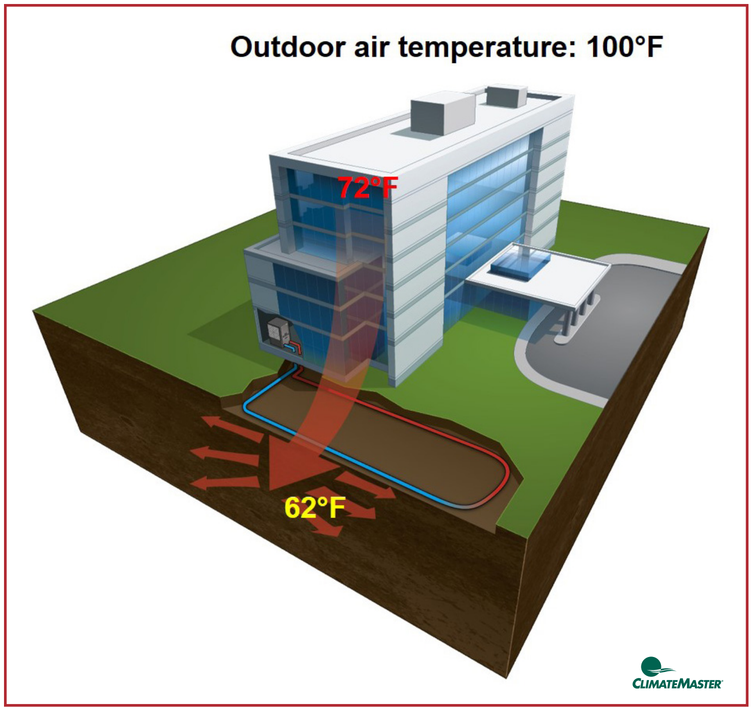

Figure 4

Longevity is another exceptional perk of a geothermal WSHP system. These systems are mostly protected from the elements, so they are long-lasting and very low maintenance and ground loops typically last a lifetime.

Finally, most or all of the equipment is totally hidden from view and operationally very quiet.

Geothermal Loop Field Options

The only caveats to geothermal heat pumps systems are (1) not every building lot has suitable acreage for a loop field, and (2) installing the loop field can be expensive.

There are four basic types of geothermal loop fields:

Pond Loop. If there is a nearby pond or other water source, this is typically the least expensive way to install a loop field. This type of installation involves floating and sinking the piping into the water instead of burying it in

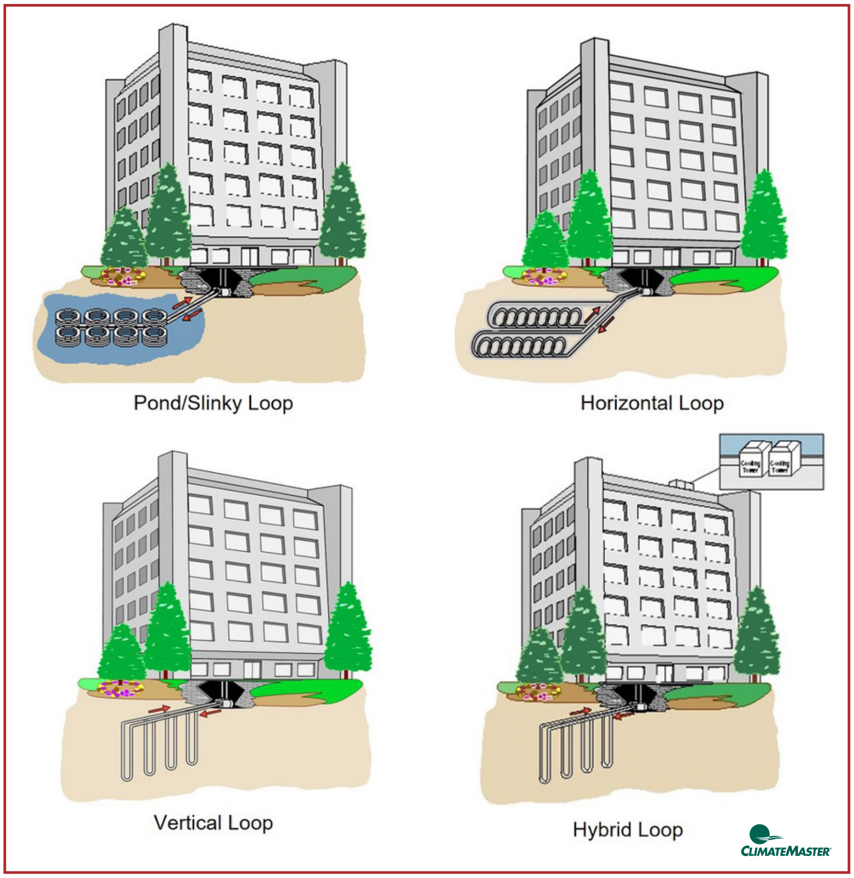

Figure 5

the earth. This can be a huge savings for owners lucky enough to have a water source onsite.

Horizontal Loop. Horizontal loops are usually just a few feet from the surface and are installed in trenches that are cut approximately five to six feet into the earth. Straight pipe installations require significant land to allow for sufficient heat transfer and spacing. A coiled or "slinky" loop configuration can be applied to minimize the lot space required for a horizontal installation.

Vertical Loop. Vertical loop fields are the most expensive type of loop field to install but may be an owner's only option if there isn't a pond or sufficient acreage to install a horizontal field. Vertical fields require well drilling equipment to drill deep holes to allow for sufficient heat transfer surface between the earth and the hydronic loop. The deeper the well, the more costly and potentially problematic the installation can be, depending on the geological make-up of the site.

Hybrid Loop. In many cases, a hybrid approach, one that utilizes a ground loop and closed-loop cooling tower is the best solution. Hybrid systems work well in buildings with load profiles that are distinctly cooling dominated. In the South, we typically size the well field for the heating load only and use a smaller closed-loop cooling tower to help offset any supplemental cooling needed during the summer. This lowers the installed cost of the system by reducing the field size.

Every building is unique, and most sites have their limitations. It is up to the engineer to help the owner decide which of the above solutions will work best.

Summary

WSHP systems offer tremendous advantages to facilities of all types. From energy efficiency to flexible design, they are perfectly suited for building owners who are increasingly opting for more sustainable building strategies. A central hydronic loop that serves both heating and cooling needs lies at the heart of a WSHP systems efficiency and flexibility to grow to meet the changing needs of any building.

For more information on WSHPs, please visit the JMP Study Hall at **www.jmpcoblog.com**.

Learn more at

jmpco.com

JMP