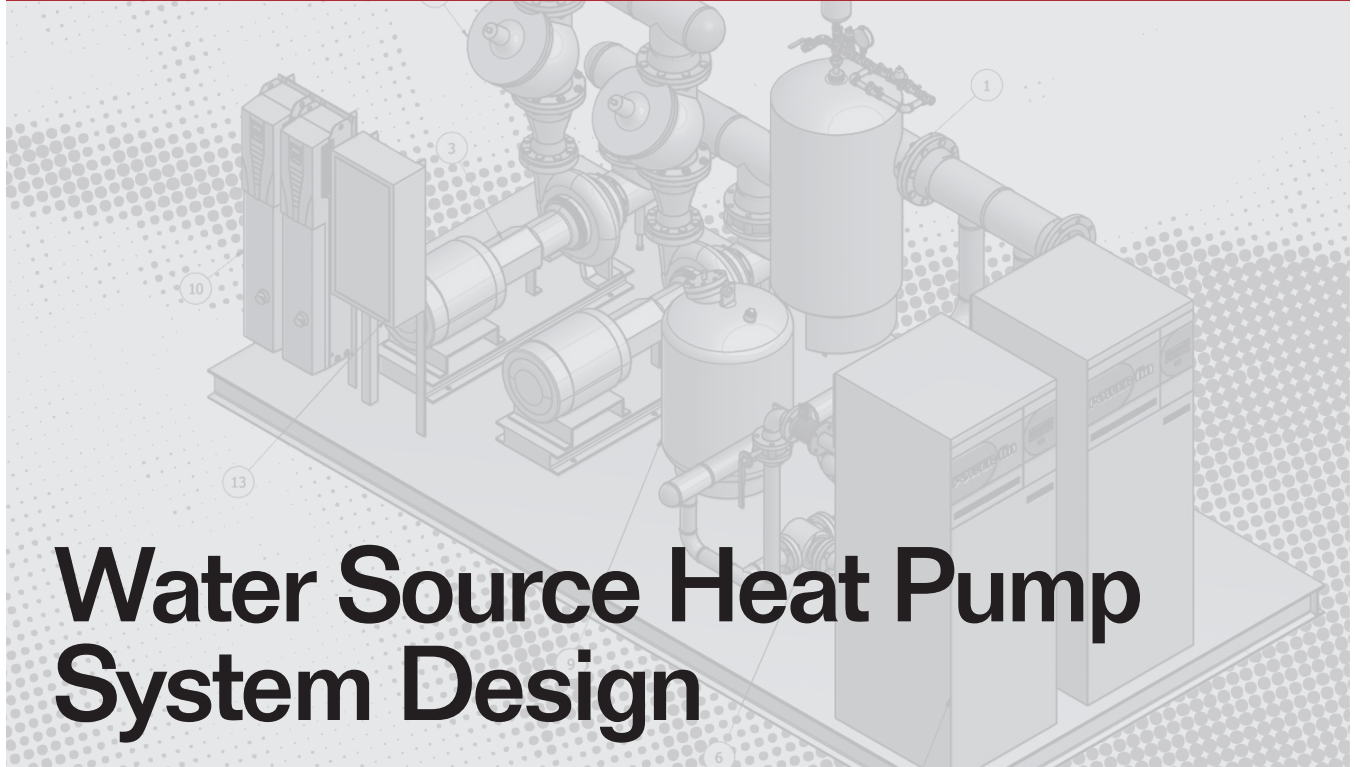


WHITEPAPER



Water Source Heat Pump System Design

JMP Equipment Company



A successful water source heat pump (WSHP) design for a commercial or multi-unit residential building must incorporate suitably sized and integrated air-side and water-side components. This whitepaper will explain in reasonable detail how to approach both the airside and waterside design in a WSHP system.

How to Calculate Outside Air Requirements

All commercial buildings require some strategy for the delivery of fresh, filtered outside air. Fresh air helps dilute indoor pollutants (carbon dioxide, allergens, etc.) which can increase allergic reactions and asthma, as well as exacerbate the spread of viral diseases from coughing and sneezing. Insufficient fresh air in interior space adversely affects student and worker performance, increases absenteeism, and reduces productivity.

In traditional centralized HVAC systems, air handlers and fan coil units are typically incorporated into the design for fresh air

intake and delivery. In WSHP systems, the approach is different, and fortunately less costly and complex. In this type of system, fresh air is supplied directly to the WSHP unit serving the individual zone. Because of this, WSHPs typically require only a small amount of ductwork compared to traditional systems, which often require hundreds of feet in sheet metal ductwork at various dimensions.

Regardless of the type of system you have, the first step in designing any fresh air delivery system is calculating how much outside air is required for the specific application.

The prescriptive paths are laid out in detail in *ANSI/ASHRAE Standard 62.1, Ventilation for*

Building Example for Calculating Outside Air	
Building Type	Office
Building Size	45,000 sq ft
Interior Spaces/sq ft	Office Space – 43,000 sq ft Breakroom – 2,000 sq ft
Location	Charleston, SC
Occupancy	225

Table 1

Acceptable Indoor Air Quality.¹ In this paper, we will illustrate the ANSI/ASHRAE method using the example of an office building with the characteristics shown in Table 1.

ANSI/ASHRAE Standard 62.1 gives three procedural options for determining the minimum outdoor (OA) airflow rate, (1) Ventilation rate procedure (VRP), (2) the indoor air quality procedure (IAQP), and (3) the natural ventilation procedure (NVP). Here in the Southeast, because of the added humidity, we generally apply the VRP or IAQP procedure. For this example, we will apply the VRP procedure to calculate the outdoor air

requirement for a space consisting of office and breakroom areas.

Using the VRP procedure, the first thing we must do is consult the Minimum Ventilation Rates in Breathing Zone table in Standard 62.1² to find the CFM per person required in an office space and breakroom space. ASHRAE tells us that in office building 5 CFM of outdoor air per person is required (Table 2). Next, we have to look at the size of our building and determine how much CFM we need for the area. Per ASHRAE, we need 0.06 cfm/ft² for office space and 0.12 cfm/ft² for the breakroom.

Occupancy Category	People Outdoor Air Rate R _p		Area Outdoor Air Rate R _a		Default Values	Air Class	OS (6.2.6.14)
	cfm/person	L/s·person	Cfm/ft ²	L/s·m ²	Occupant Density		
					#/1000 ft ² or #/100 m ²		
Office Buildings							
Breakrooms	5	2.5	0.12	0.6	50	1	
Main entry lobbies		2.5	0.06	0.3	10	1	✓
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3	2	1	
Office Space	5	2.5	0.06	0.3	5	1	✓

Table 2. The complete table (Table 6-1) detailing the minimum “People Outdoor Air Rate” and “Area Outdoor Air Rate” for all different types of buildings can be found in ASHRAE Standard 61.2. We’ve included a portion of the table (above) for our example.

The equation for determining the required outdoor airflow in a given breathing zone of an occupiable space is as follows:

$$V_{bz} = R_p \times P_z + R_a \times A_z$$

Where,

A_z = zone floor area, the net occupiable floor area of the ventilation zone, ft²

P_z = zone population, the number of people in the ventilation zone during use

R_p = outdoor airflow rate required per person as determined from Table 6-1

R_a = outdoor airflow rate required per unit area as determined from Table 6-1

$$V_{bz} = (5 \text{ cfm} \times 225) + (0.12 \text{ cfm/ft}^2 \times 2000 \text{ ft}^2) + (0.06 \text{ cfm/ft}^2 \times 43000 \text{ ft}^2) \\ = 3945 \text{ CFM Total Required Outside Air}$$

In this example, we calculate our total outside air required to be 3945 CFM. (Note that in the real world, this calculation would be more complex depending on the types of spaces and occupancies in a building. You would also want to consult Standard 61.2, Section 6.2 for any exceptions that might apply to your building type.)

Introducing Outside Air into a Space

Now that you know how much outdoor is required, the next step in this process is to determine how you will bring the air into a space that is served by a WSHP. You have two options:

- (1) Outside air can be introduced into the space by ducting it in from the outdoors. We typically do not recommend this method because it will likely require additional ductwork and diffusers, and because introducing this unconditioned air directly into the space may cause discomfort to occupants that are close to the point where the air is introduced.
- (2) Outside air can be brought in through the WSHP via a duct that is connected to the return air duct that sits between the return air from the space and the WSHP. This method will require continuous fan operation while the space is occupied, but at least the outdoor air will be conditioned before it enters the space.

Cooling System at Dehumidification Design Conditions							
Based on:							
ASHRAE 0.4% Dehumidification Design Day							
10% Untreated Outside Air							
Location	Outdoor DB	Outdoor WB	Return DB	Return WB	Mixed DB	Mixed WB	Humidity
Charleston, SC	84.4F	80.2F	75F	62.4F	76.0F	64.5F	54%
Nashville, TN	82.9F	77.1F	75F	62.4F	75.8F	64.1F	53%
Asheville, NC	77.4F	73.1F	75F	62.4F	75.2F	63.6F	53%

Table 3

Incorporating Dehumidification

Regardless of which method you choose for introducing air, the WSHP must be sized for a dehumidification/cooling design day. The chart below gives an example of what those design parameters might look like in the southeast (Table 3).

Note the mixed dry bulb (DB) and wet bulb (WB) temperatures of the outdoor and return air on a design day in each of the southern

cities. Without mechanical dehumidification, a WSHP system may be able to maintain reasonably comfortable indoor humidity as long as the system is fully loaded, assuming it is sized to handle the latent load. It's when the system is at non-design day or part load conditions that problems are likely to occur, especially when the weather is warm and humid.

Figure 1 shows what happens when our example system is at part load on a warm,

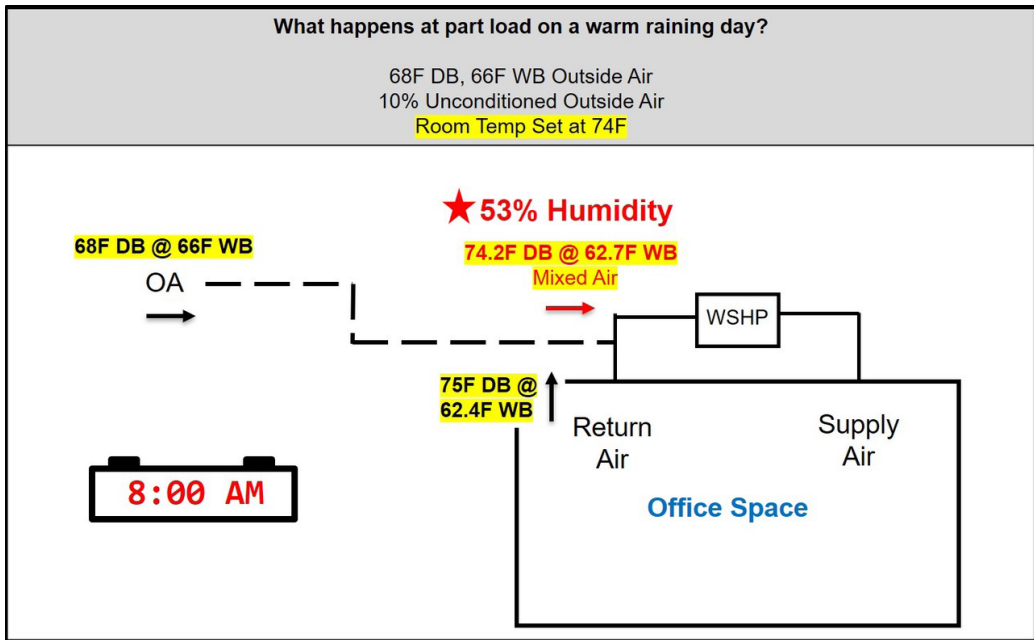


Figure 1

rainy day. At 8:00 AM, the outdoor air is at 68°F DB with a wet 66°F WB. This is the air we'll be introducing into the space as people come to work. Notice that the thermostat is set at 74°F and our mixed air temperature to the WSHP is 74.2°F. The WSHP is not yet operating and already the supply air humidity is up to 53% RH.

Now let's say that it is 10:00 AM and the outdoor air is 72°DB at 72°WB. The outdoor air is fully saturated and it is raining outside. Our mixed supply air temperature is 74.6°F DB with a 65.7°F WB. The humidity of the

supply air to the WSHP is now up to 63% RH and our thermostat is still set at 74°F. Because the thermostat only sees the *sensible* load of the building, the WSHP only comes on for a short time before it reduces the supply air temperature from 74.6°F to our 74°F setpoint—not enough to effectively dehumidify the air, which is now uncomfortably humid at 63% humidity. (Figure 2)

The only option we have for dehumidification is to over-cool the room. Either way, occupants are going to be uncomfortable.

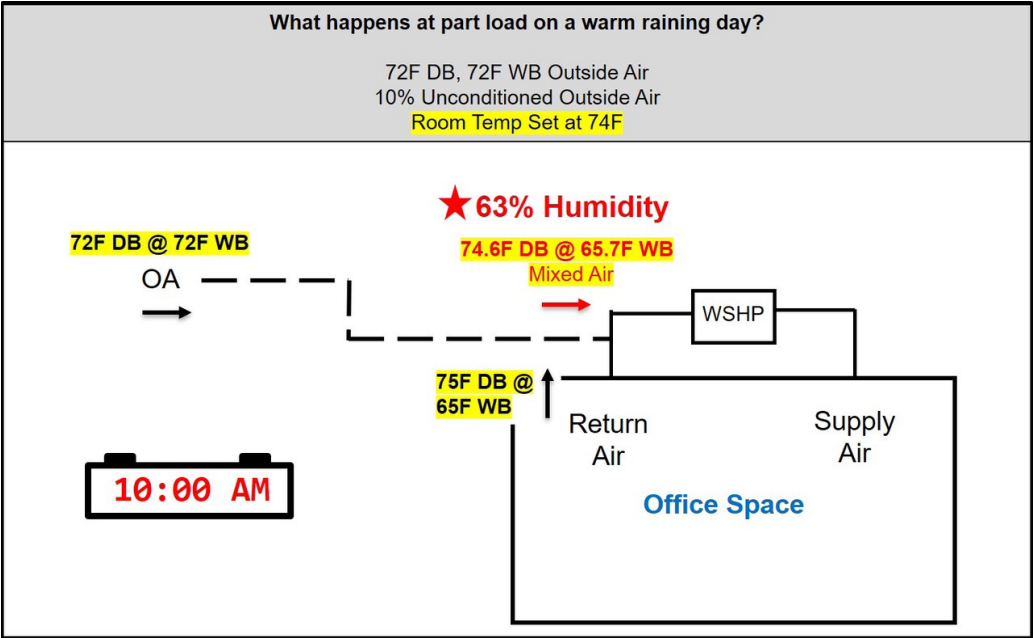


Figure 2

By noon, the outdoor air is 74°F DB at 72°F WB. Our mixed air temperature is now 74.8°F DB at 68.4°F WB. Our mixed air to the WSHP is now very moist at 73% RH. And, once again, since the WSHP is only slightly

loaded with our 74°F thermostat setting, it will not be running long enough to dehumidify the space. Our occupants are now extremely uncomfortable and the room feels very muggy (Figure 3).

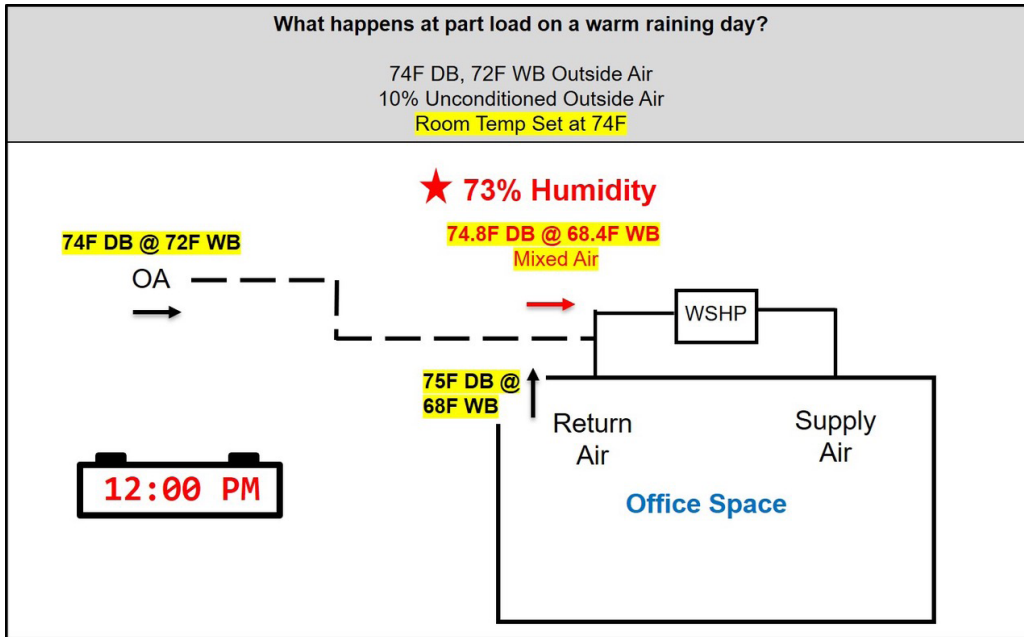


Figure 3

Table 4 summarizes the conditions in our example as the day progresses. We are bringing in 72°F outdoor air that has a humidity close to 100% RH. There is no external heat load outside so the WSHP turns off, while the fan continues to bring more moist outdoor air into the building.

Here in the southeast, this is a fairly common weather scenario, especially during the shoulder seasons. This example illustrates precisely why we need to be able to condition outdoor air *before* we introduce it to the indoor space.

What happens at part load on a warm raining day?							
72F DB, 72 WB Outside Air, 10% Outside Air							
Room Temp Set at 74F							
Mixed Air Conditions							
Unconditioned Outside Air							
Time	Outdoor DB	Outdoor WB	Return DB	Return WB	Mixed DB	Mixed WB	Humidity
8:00am	68F	66F	75F	62.4F	74.2F	62.7F	53%
10:00am	72F	72F	75F	65F	74.6F	65.7F	63%
12:00pm	74F	72F	75F	68F	74.8F	68.4F	73%

Humidity is an issue!

Table 4

Options for Conditioning Outside Air

What options do we have for conditioning outdoor air before it is brought into a space that is served by a WSHP? (Note that by “condition,” we primarily mean *dehumidification*, at least here in the southeast.) Ideally, the conditioned air should be drier than the air in the space. This usually involves overcooling the air, so some amount of reheat is often required, especially during part-load conditions.

There are three basic options for conditioning outdoor air before delivering it to the space. Each has its advantages and disadvantages to consider for the given application.

Option 1: Dedicated Outdoor Air System.

Dedicated outdoor air systems (DOAS) are the most common choice for conditioning outside air before it is introduced to the heat pump or the space. DOAS units provide conditioned outdoor air to many types of HVAC systems, not just WSHPs, so they are quite common on commercial-size systems. These units include both a cooling coil for dehumidification and a reheat coil that uses recovered heat from the refrigeration circuit to heat the air to the desired dry-bulb temperature.

DOAS units are popular because they can remove large amounts of moisture from the air while delivering “neutral” air that has approximately the same dry-bulb temperature as the air in the space. As a result, the WSHP need only be sized for the sensible load, which may lower the cost of the overall installation, depending on the number of heat pumps in the system. Sometimes, the DOAS can supply even cooler air, thus relieving the WSHP of some of the sensible load. This can work as long as no reheat is required.

Option 2: Energy Recovery Unit. Energy recovery units (ERU) condition outdoor air via a desiccant media wheel or another device that can exchange moisture and BTUs with the building exhaust air. These units have a low operating cost and are often used in combination with smaller DOASs to help keep costs down. However, ERUs do not typically have enough dehumidification capacity on their own to manage the latent load of a building, especially on warm, rainy days. Therefore, an ERU is typically a “part” of a solution rather than a stand-alone strategy. Furthermore, ERU components (wheel, filters, motors) require regular inspection and maintenance to remain efficient and operable long-term, which could be a problem for facilities with limited or no maintenance staff.

Option 3: WSHP with Dehumidification and Built-in Reheat.

Standard WSHPs do not typically provide sufficient dehumidification on part-load cooling days, especially if the outdoor humidity is very high. The units tend to run for very short periods, satisfying the sensible load long before adequate dehumidification takes place. However, some WSHP manufacturers now offer their equipment with integral dehumidification and reheat, allowing owners to avoid the cost of a DOAS and/or ERU. A WSHP with a dehumidification/reheat option can often provide cost-effective dehumidification, depending on the type of reheat that is used.

Reheat options for WSHPs include hot gas, electric, or hot water. Regardless of the heat source, outdoor air is overcooled for the purpose of dehumidification and then reheated to the thermostat setting.

- Hot gas reheat works by passing the hot discharge gas from the compressor through a separate air coil to warm the dehumidified outdoor air to a suitable space temperature. Unfortunately, these systems

rely on complex controls to operate and contain multiple valves and complex piping. In addition, the amount of reheat tends to fluctuate so supply air temperature and humidity tend to be inconsistent.

the reheat coil, so space temperature remains consistent and comfortable at all times, regardless of outdoor conditions. (Figure 4).

- Electric reheat coils provide more reliably conditioned air but increase installation costs due to their higher electrical requirements and loads. Electric reheat also yields higher operating costs.
- Hot water reheat is the best option in terms of simplicity, efficiency, and reliability. WSHPs with a hot water reheat option include an internal pump that circulates warm condenser water through the hydronic reheat coil during the “cooling with reheat” mode of operation, warming the dehumidified supply air before it enters the space. The amount of reheat that occurs is dependent on the setpoint and the difference between the setpoint and the supply air temperature. A modulating mixing valve and a proportional controller maintain precise control of water through

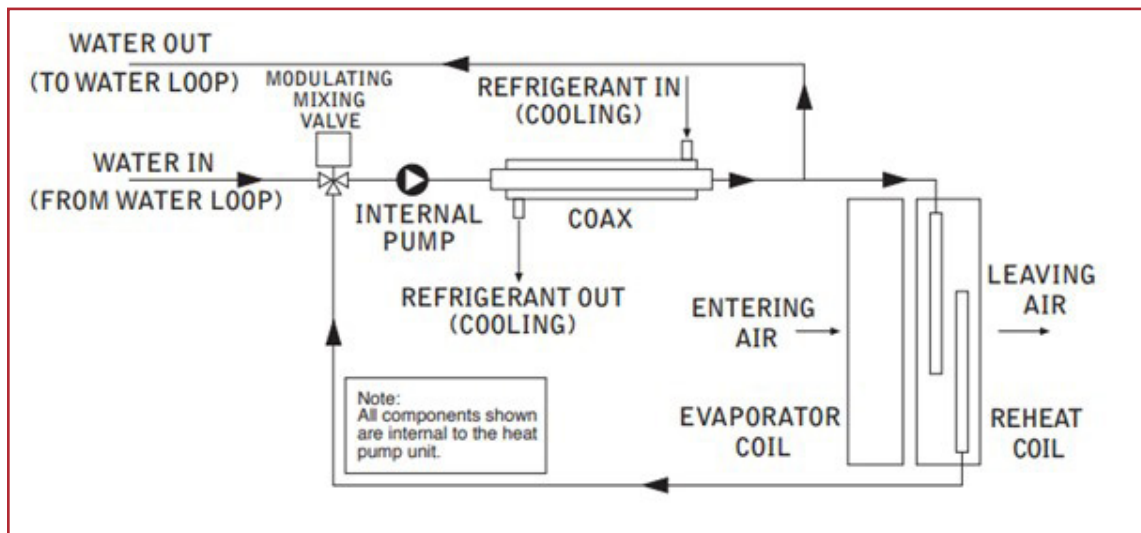


Figure 4. Internal schematic of a WSHP with hot water reheat.

Water Side Components and Considerations

What components make up the waterside of a WSHP design besides the heat pumps themselves? And what “best practices” should engineers observe to optimize the efficiency and longevity of waterside equipment?

The waterside of a multi-zone WSHP system is quite very basic. In addition to the piping, there are only three major components:

- 1. A cooling tower for rejecting heat during the cooling season
- 2. A boiler for adding heat to the circulating water during the heating season
- 3. Pumps to serve the boiler, cooling tower, and WSHP system

There is no chiller or condenser water loop. And since a WSHP system is always “redistributing” BTUs as needed and each WSHP unit contains its own refrigeration cycle,

the boiler and cooling tower never have to operate simultaneously, even when there is a simultaneous demand for heating and cooling.

Cooling Towers. Open or closed cooling towers may be used in a WSHP system, although we recommend a closed circuit cooling tower (CCCT) for a few reasons. CCCTs have their own internal heat exchanger so there is no need to specify or find space for a separate one. This will also reduce the amount of space required inside the building. A closed-loop system protects the WSHPs from environmental debris and corrosion, which improves longevity and energy costs. Finally, CCCTs may have a lower first cost because of a reduction in pumping requirements, floor space, and added filtration that may be needed to keep a separate heat exchanger from fouling. CCCTs can even be installed inside the building if the owner wants to keep the equipment hidden from view. (Figure 5)

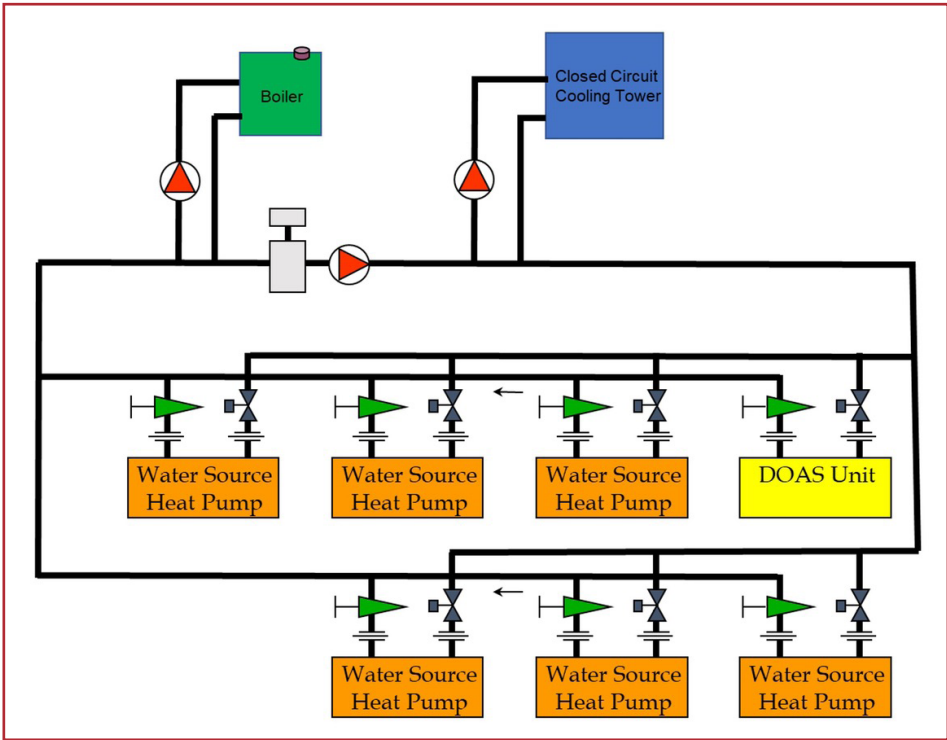


Figure 5. Closed-loop cooling towers are recommended for WSHP system applications.

If for whatever reason, an open tower is chosen, it is necessary to select a separate heat exchanger for installation between the system loop and the cooling tower loop. The WSHP loops must be closed. We recommend an enhanced high turbulence shell & tube heat exchanger for this application because they are less susceptible to fouling and are easier to service than plate & frame heat exchangers yet still provide a close temperature approach.

Boilers. A boiler should be used as the heat source in a WSHP application, fulfilling the role that the earth would play in a geothermal heat pump system. Hydronic heat from boilers allows the owner to capitalize on BTU sharing of the WSHP system. A decoupled heating strategy like electric strip heaters for space heating would completely defeat the purpose of having a WSHP system. Gas-fired condensing boilers offer optimal efficiency, however electric boilers can also be used if gas utility is not available, or if the owner simply prefers electric or requires it to meet new carbon emissions reduction guidelines.

Pumps & VFDs. Finally, the engineer must decide what types of pumps to use, inline or base mounted end-suction. For ease of maintenance, we recommend base-mounted pumps with a center drop-out spacer coupler. This allows easy removal of the bearing frame and rotating element without disturbing the pump end pipe alignment or motor electrical components. Each pump should also be equipped with variable frequency drives (VFDs) to lower pump speed when demand is low.

Want to Shortcut Your WSHP System Design Process?

Instead of selecting every component for the “energy” portion of your WSHP system, you can choose a factory-engineered and assembled package that includes boilers, air separators, pumps, controls, and even a closed circuit cooling tower, all pre-piped and mounted on a single skid. These “Water-Source Heat Pump Energy Plants” come complete with all the necessary wiring and supply and return connections. For more information contact your JMP representative.

¹<https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2>

²https://www.ashrae.org/File%20Library/Technical%20Resources/Standards%20and%20Guidelines/Standards%20Addenda/62_1_2013_p_20150707.pdf

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