WHITEPAPER

Water Source Heat Pump Control and Optimization

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This whitepaper provides a thorough overview of controlling small to large commercial WSHP systems, and design tips for optimizing energy efficiency while keeping total cost of ownership (TCO) low.

Control of commercial WSHP systems can be as simple as individual unit zone control, but most WSHP systems will require at least a rudimentary building management system (BMS). Simple or complex, the key to controlling and optimizing any WSHP system is making the most of the BTU storage in the water loop. The loop is the "battery" from which BTUs will be shared as needed by individual heat pumps to meet their corresponding loads.

Properly sized heat pumps in a WSHP system can meet corresponding zone demands as long as the loop temperature stays between 50°F and 90°F. This is called the "deadband" range. As long as the loop is in deadband range, neither the boiler nor cooling tower will need to be activated to meet help satisfy the load, regardless of the season or outdoor temperature.

Component Setpoint Control

Commercial WSHP systems usually include most if not all of the following integrated components: heat pumps, boiler, cooling tower, dedicated outdoor air system (DOAS), and variable speed pumps. Not surprisingly, control complexity increases with the number of integrated components. But control complexity may also depend on the needs and budget of the owner.

We recommend the following temperature control settings for a WSHP system with a cooling tower and boiler:

Dead Band Range: A loop temperature range of 50°F to 90°F is typically sufficient to maintain load without calling on the cooling tower or boiler, as long as individual units are appropriately sized for the load they serve.

Closed Circuit Cooling Tower START Set Point: When the water loop temperature reaches a set point of 90°F, the system should be controlled so that the cooling tower dampers open and the spray pump is activated. This alone may be enough to cool the water loop without actually turning on the cooling tower fan.

Cooling Tower Fan START Set Point: If the water loop continues to rise, the cooling tower fan should be controlled to start rotating when the loop temperature reaches 95°F.

Maximum Loop Temperature Range: 50°F to 102°F is the operating range of the loop with either the boiler or cooling tower operating. Cooling Tower OFF Set Point: Once the loop temperature is cooled to 80°F, all cooling tower components (fan, spray pump, and dampers) should deactivate.

Boiler START/STOP Set Point: When the loop temperature drops to 50°F, the boiler should activate and remain active until the loop reaches 65°F. Recommended boiler setpoint is 60°F.

How Sophisticated Does the Building Management System (BMS) Need to Be?

Small commercial systems with a geothermal ground loop are fine with simple WiFi-enabled thermostats for unit control. This allows you to control the heat pumps with an iPad or laptop and troubleshoot individual WSHP alarms. Small commercial systems with towers and boilers could also utilize this approach and just let the DOAS, boiler, cooling tower, and pump operate based on their individual controls.

A building will benefit from a traditional BMS setup if any of the following is required (or desired):

- Centralized alarms for equipment faults
- Integrated control of DOAS, boiler, cooling tower and/or boiler
- Energy optimization (e.g. morning start-up, nighttime setback, etc.)
- Tower freeze protection
- Remote reset of individual units that may go off on an alarm
- DDC controls for monitoring the status of all equipment
- Tower freeze protection

Energy optimization may be as simple as automatic on/off control of units to correspond with periods of occupation. A BMS can gradually stage units on in the morning so that the entire system doesn't start up at once which could cause the utility to increase the owner's electrical demand threshold. This approach is common in elementary school applications.

Larger educational, medical, governmental facilities, etc. will likely require more advanced BMS capability, with most if not all of the functionality listed above, along with enhanced, user-friendly graphics.

Incorporating Freeze Protection for Cooling Towers

Most commercial WSHP systems require a cooling tower, which can either be an open or a closed-circuit design. If the system is in a part of the country that periodically sees sub-freezing temperatures during the heating season, it must be designed and controlled with freeze protection in mind. Mother Nature can be particularly unforgiving to cooling towers when it is cold out, so it is best not to tempt fate. A cooling tower can freeze up in a surprisingly short period, damaging expensive equipment and resulting in unplanned downtime.

Open cooling towers and closed circuit cooling towers differ slightly in their freeze protection needs. However, assuming the cooling tower is installed outdoors in a climate that is susceptible to freezing temperatures, the following measures and precautions apply to *both*:

- Do not operate the cooling tower when there is no cooling load. Keep in mind that in many buildings year-round cooling is required. However, the cooling tower should not operate unless there is some active cooling load. Without warm water flowing through the cooling tower, it is more susceptible to freezing.

- Cold water basins should be equipped with electric heaters to prevent the basin water from freezing. The heater should be sized for the coldest weather a geographical region may see – typically 0°F or -20°F.

- Basin heaters should be equipped with a thermostat that will turn them on when the temperature drops below 40°F. A contactor is needed to activate the heater when the temperature drops below this set point.

- A low water cut-off control is required to prevent the heater from coming on if the basin is dry.

- The cooling tower fans should be equipped with a cut-off switch to stop rotation if the fan blades start to vibrate excessively due to ice formation.

- All outdoor cooling tower water piping and make-up water piping should be insulated and installed with heat tracing.

Additional Freeze Protection for Closed-Circuit Towers

In addition to the above measures, closed-circuit cooling towers require freeze protection of the internal heat exchanger if glycol is not being used in the hydronic system. We highly recommend providing positive closure dampers on all closed-circuit cooling towers to minimize the heat loss from the heat exchanger to the outdoors when the tower is not operating. If water is used as the heat transfer medium, the cooling tower loop pump should be operated during periods of low temperature to provide a small amount of warm water thru the heat exchanger. With the dampers closed, this will keep the heat exchanger from freezing.

Here is a typical freeze protection sequence for a closed circuit cooling tower (Table 1):

Condition	Resulting Action
No cooling demand	Dampers close
Basin water drops to 40°F	Basin heater activates
Outdoor air drops to ≤ 35°F	Tower loop pump activates
Loop temperature continues to fall due to pump failure	Alarm notification

Table 1

The coils in a closed-circuit cooling tower heat exchanger can rupture if the heat exchanger freezes. That's why most closed-circuit cooling towers in the north use a mixture of water and glycol in the hydronic system to keep the fluid from freezing. Although you lose a small amount of heat transfer capability, this mixture in the hydronic system reduces the freezing point. The mixture of glycol and water can be adjusted to change the freezing point to match the minimum temperature your system might see. It is important to check with the glycol manufacturer to see what percentage of glycol is recommended to prevent freezing at a given temperature.

While glycol may seem unnecessary in areas further south, keep in mind that if a facility loses power in an ice storm, it also loses operation of the pump, which keeps the heat exchanger from freezing. Glycol will prevent this from happening and also simplify the freeze protection.

Heat Sinks: Optimizing Total Cost of Ownership (TCO)

One of the greatest advantages of WSHP systems is that they can be coupled with various types of heat sinks (see Figure 1), giving users greater opportunity to optimize the system for the lowest total cost of ownership.

So far, we've talked mostly about WSHPs that utilize cooling towers and boilers to add and remove BTUs into the loop, but the earth or a natural or manmade water source can do the same job. This type of WSHP system is usually referred to as a geothermal system, and if the opportunity is there, it typically offers the highest operational efficiency. The EPA ranks geothermal systems as the most cost-effective systems for heating and cooling buildings. Geothermal is also considered a renewable energy source.

Choosing the loop field (heat sink) design ultimately comes down to three factors::

1. Is there sufficient land or a nearby water source (e.g. pond) to support the heat loss characteristics of the building?

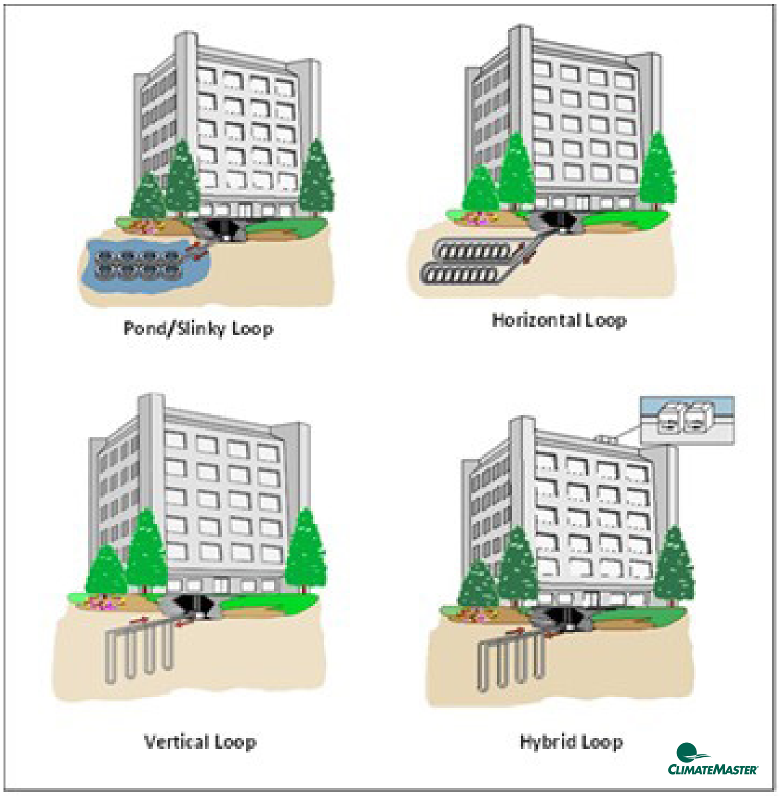
2. Does the owner have the budget to pay for the installation of the loop field?

3. How committed is the owner to the long-term efficiency and sustainability associated with a geothermal system?

A nearby lake or pond can make the decision a bit easier, since installing a loop in water is significantly less expensive than drilling or cutting into the earth. Pond or lake temperatures tend not to be as stable as ground temperatures, depending on the water depth, but heat transfer is still extremely efficient.

In this type of installation, the loop pipe is weighted with concrete blocks and placed at the bottom of the lake or pond. The body of water needs to be at least 9 ft deep and large enough to accommodate the building load. A minimum of 300 sq ft per ton is typically required for year-round heating and cooling.

In the absence of a pond or lake, a loop field can either be installed horizontally or vertically on the owner's land. If there is sufficient land with suitable soil properties, a horizontal loop can be installed in 4 to 6 ft trenches for less money than installing a vertical loop, which involves expensive well-drilling to penetrate deeply into the earth. Horizontal loops require quite a bit of land, but they can be installed under parking lots or even sports fields.



Not every owner has the resources (land or otherwise) to install a full capacity geothermal system. In these cases, a hybrid solution that relies on a smaller geothermal loop as a heat sink and a cooling tower to help reject BTUs during the hotter months can be an efficient and affordable alternative.

In most cases, this type of hybrid solution means sizing the geothermal loop for the heating load only and adding a cooling tower sized for the difference in the capacity of the design heating and cooling loads to supplement the geothermal loop during the hottest times of the year. This is an excellent option in the southeast where the cooling demand is greater than the heating demand because a hybrid design eliminates the installation and operational expense of a boiler while reducing the size and installation cost of a geothermal loop. Hybrid systems often deliver the best ROI of all HVAC system designs, WSHP or otherwise.

Waterside Economizing with WSHPs

Just about every major water source heat pump (WSHP) manufacturer now offers equipment with an integral waterside economizer, no doubt to give engineers a straightforward path to meeting the following ASHRAE 90.1-2013 requirement for air or waterside economizing (see Table 2).

ASHRAE 90.1 Waterside Economizers Requirements

6.5.1 Economizers. Each cooling system that has a fan shall include either an air-to-water economizer meeting the requirements of Sections 6.5.1.1 through 6.5.1.4.

Exceptions: Economizers are not required for the systems listed below.

TABLE 6.5.1A Minimum fan-cooling size for which an economizer is required for comfort cooling

Climate Zones	Cooling Capacity for which an Economizer is Required
1a, 1b	No economizer required
2a, 2b, 3a, 4a, 5a, 6a, 3b, 3c, 4b,4c, 5b, 5c, 6b, 7, 8	≥ 54,000 Btu/h

Table 2

However, while the economizer requirement applies to just about every climate zone in the US, a closer read of the standard shows it is very likely not required on the majority of multi-zone commercial WSHP systems. If the cooling efficiency of the WSHP unit meets or exceeds the efficiency improvement requirements per ASHRAE Table 6.3.2, an economizer is not required (see Table 3).

Eliminate Required Economizer for Comfort Cooling by Increasing Cooling Efficiency	
Climate Zone	**Efficiency Improvement**
2a	17%
2b	21%
3a	27%
3b	32%
3c	65%
4a	49%
4b	49%
4c	59%
5a	74%
5b	59%
5c	74%
6a	56%
6b	64%
7	72%
8	77%

Table 3: If a unit is rated with an IPLV, IEER, or SEER, then to eliminate the rquired air or water economizer, the minimum cooling efficiency of the HVAC unit must be increased by the percentage shown. If the HVAC unit is only rated with a full load metric like EER or COP cooling then these must be increased by the percentage shown.

Currently, there is very limited information about what efficiency gains an economizer might yield over the efficiency of the WSHP system itself. It may increase long-term operational costs, not to mention system complexity. Fortunately, ASHRAE 90.1 includes exceptions within the standard that give engineers plenty of room to prioritize the efficiency of the overall system over the singular strategy of an economizer. But before we get to that, let's explore what makes these two energy-saving strategies potentially incompatible.

Water Temperature Requirements: Economizer versus operating in the WSHP Deadband

The point of conflict between typical WSHP operation and WSHP economizer operation is likely to occur when it is cold outside, but part of the building still needs cooling.

If the system has been designed to operate in accordance with ASHRAE 90.1-2013 Section 6.5.1.2, then the fluid economizer would provide up to 100% of the expected system cooling load whenever the outdoor temperature drops to 50°F dry bulb/45°F wet bulb or below. To provide full cooling, the economizer in each unit may require supply water temperature to be as low as 45°F. Meeting this requirement means resetting the WSHP loop temperature below the preferred deadband temperature range (typically 50°F to 90°F) of the system until cooling is no longer required. This sidelines the most valuable asset of a WSHP system, its battery capacity.

If we reset a WSHP loop to 45°F, then the heat pumps in heating mode become less efficient. Simultaneous heating and cooling are the key to WSHP system efficiency. This is what allows us to maximize the battery capacity of the water loop while minimizing the use of the cooling tower and boiler.

The efficiency penalty for resetting the loop temperature to 45°F can be significant. If the coefficient of performance (COP) for operating a WSHP at 70°F is 5.9, the COP for the same system drops to 3.6 at 45°F. This could interfere with ASHRAE 90.1-2013 compliance since Section 6.5.1.5 Economizer Heating System Impact states that the HVAC system design and economizer control shall be such that economizer operation does not increase the building heating energy use during normal operation.

Here are a few other things to consider before including waterside economizers in your WSHP system design:

- The addition of a waterside economizer coil increases the pressure drop through each zone. (Note: ASHRAE 90.1-2013 Section 6.5.1.5 Maximum Pressure Drop states that the water-to-water heat exchanger used as part of the economizer shall be less than 15 ft or an additional secondary loop must be created with its own recirculation pump.)

- The economizer coil also creates additional airside pressure drop through the unit. This pressure drop will exist whether we are operating in economizer mode or not.

- Operating in economizer mode means operating the cooling tower to make 45°F water, regardless of the season. This gets complicated (and more expensive) in winter since cold air holds less moisture. Approach and wet bulb temperature become critically important for the effective operation of the cooling tower in winter. And remember, under normal WSHP operating conditions, you typically would not have to operate the cooling tower at all in the winter as long as the loop stays within deadband.

- What is leaving water temperature off WSHP in heating mode? If we bring 45°F to a WSHP in heating mode the leaving water temperature could be in the 30s.

- Do you need a glycol system to keep the system from tripping out due to low water temperature?

- What is your operational sequence? Again, this gets tricky in winter. Remember, the economizer is expected to provide partial cooling even when mechanical cooling is in operation.

How to Eliminate the Economizer Requirement If It Doesn't Make Sense

As we stated early, you do have options when it comes to meeting ASHRAE 90.1-2013 without having to implement waterside economizing in your design.

In our part of the country, per the International Energy Conservation Code (IECC), climate zones 3a and 4a (North Carolina, South Carolina, Tennessee, Georgia, and Alabama), the cooling efficiency of the system must be improved over code by 27% or 42% respectively to avoid the economizer requirement. We've created an easy cheat sheet to help you determine if the WSHP equipment you select for your application will allow you to meet these efficiency improvements in these zones. Click here to download the document for Increased Efficiency Requirements for Elimination of Waterside Economizers in Zones 3A and 4A.

You can also model the system using the Energy Cost Budget Method described in ASHRAE 90.1-2013 to compare the overall energy of the system you are designing with and without an economizer, regardless of what type of heating and cooling system you are using. This can be found in *Section 11.1.1 Energy Cost Budget Method Scope* and will let you evaluate whether an economizer would be more efficient for your application.

As discussed, each application should be considered individually to see if a water-side economizer makes sense. Factors such as building type, load profile, occupancy, and location need to be considered. A detailed list of exceptions can be found in ASHRAE 90.1-2013 Section 6.5.1.

Remember a WSHP system is naturally an economizer by design. This is because you can turn off the mechanical heating and cooling equipment while operating within the dead band and run off your hydronic battery. The larger the deadband, the larger your battery.

Did you know?

WSHPs can be used for radiant heat and even domestic hot water!

WSHPs can be coupled with other types of equipment to boost overall energy efficiency. For instance, you can add a heat pump to the loop to serve a zone that is exclusively heated by radiant heat. This is a great solution for a commercial warehouse with high ceiling, where forced air heating would be inefficient and ineffective. Instead of transferring water loop heat to the air in a space, a water-to-water heat pump can be used to transfer heat to an under-slab radiant heat loop so that heat is concentrated closer to the floor where the occupants are.

The same concept can be applied to domestic water heating, allowing owners to take advantage of surplus BTUs from the WSHP loop to heat domestic hot water. In this design scenario, a special type of water heater heat pump acts as a supplemental heat sink to the overall system, increasing the space cooling capacity of the WSHP system, while greatly reducing the cost of water heating. This could be particularly advantageous in buildings that have large cooling load zones such as a kitchen or laundry.

More Optimization Strategies

Engineers have many options for optimizing energy efficiency in a WSHP system. Most of these opportunities involve making the most of the part-load conditions since these systems rarely operate at peak load. Here are useful strategies regardless of load conditions.

- *Specify WSHPs with a 2-stage scroll or variable speed compressor.* These types of compressors not only save energy, but they are also less likely to short cycle and therefore provide better temperature and humidity control.

- *Use diversity factors to determine the peak "block load" for the system and size of the equipment (WSHP, cooling tower, and boiler) based on this value rather than the overall peak load.* Virtually all commercial buildings have enough demand diversity to reduce the need for capacity. This is especially true of WSHP systems which are designed to recover and transport energy to wherever it is needed.

- *Specify cooling towers or closed circuit coolers with smaller variable speed fans, and large boxes for greater heat transfer area.* The reduction in fan horsepower will more than make up for the slight increase in cost over the life of the system.

- *Choose a condensing boiler if at all possible.* Condensing boilers, while more expensive than non-condensing boilers, are perfectly suited for the extended part-load conditions associated with WSHP systems. Not only are condensing boilers more efficient at part load, but they also thrive on the low return water temperatures that a WSHP system produces.

- *Do not oversize zone WSHPs!* Doing so will undermine efficiency and create humidity issues due to the frequent on/off cycling that will occur as a result of sensible cooling loads being met before latent load.

- *Use parallel 50/50 variable speed pumps instead of a single large pump.* Two smaller pumps manifolded together are more efficient than a larger pump at part load. Plus, you get a significant amount of built-in redundancy.

- *Specify WSHPs with a modulating hot water reheat option.* A WSHP with a dehumidification/reheat option can often provide cost-effective dehumidification, and sometimes help owners avoid the cost of a dedicated outdoor air system (DOAS) or energy recovery unit. An internal pump 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. Modulating reheat can provide up to 100% "neutral" 72°F supply air even at part load (non-design) conditions.

- *Consider specifying a heat pump water heater to heat domestic water for the building.* These units often have a COP of 5 or greater, and it makes more sense to use BTUs rejected from the cooling system to heat water than it does to reject them through the cooling tower. A hot water storage tank can be added to "store" BTUs for the water heater throughout the day so they don't go to waste.

- *Use an automatic flow regulating balancing valve to control flow through the WSHP.* Based on the required delta T for the unit, these valves prevent the overflowing of the WSHP. If the system is variable flow, consider installing an automatic balancing valve on each pump. This helps ensure proper water through the heat pump (when the compressor is operating) as the system flow rate changes.

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