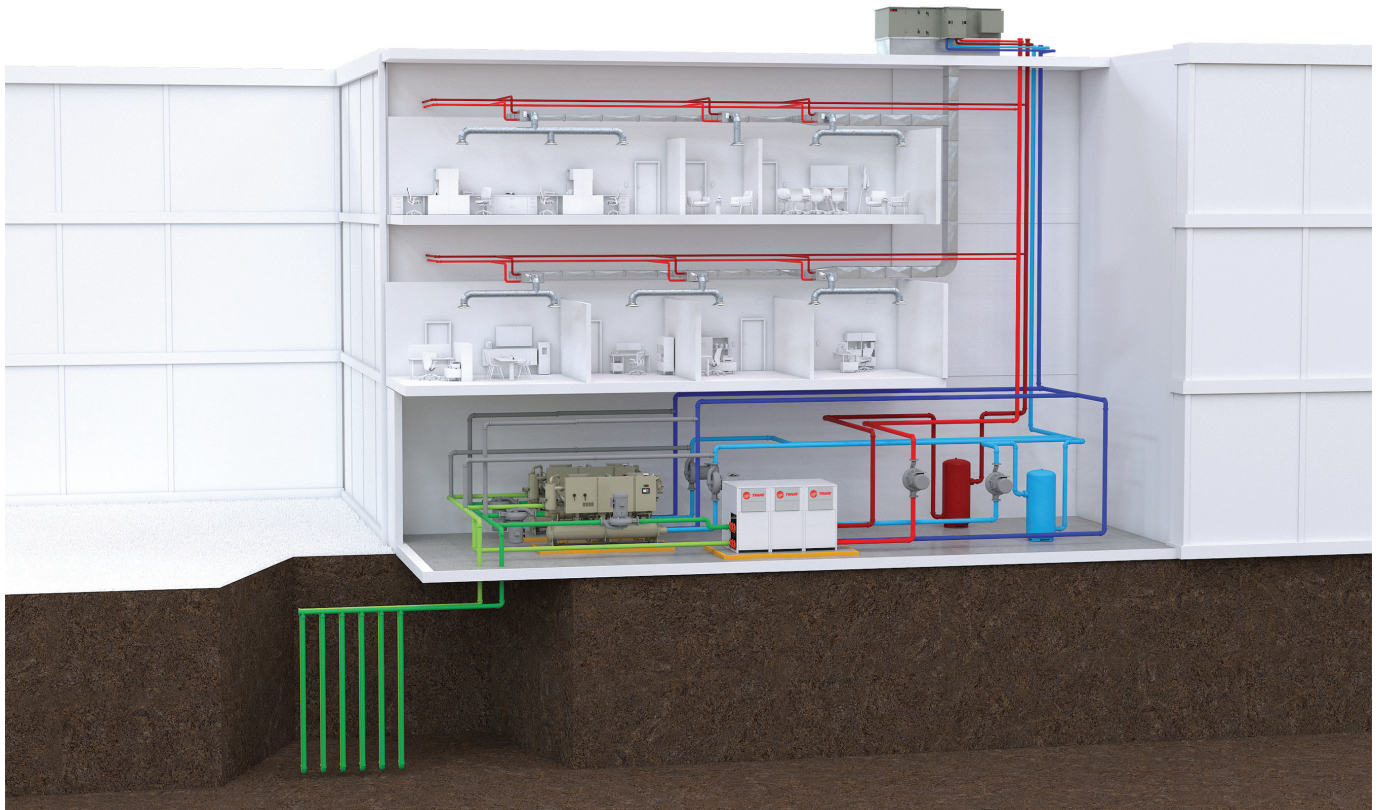




Application Manual

Central Geothermal Systems





Central Geothermal Systems

Author Ben Sykora, Application Engineer



Preface

As a leading HVAC manufacturer, we deem it our responsibility to serve the building industry by regularly disseminating information that promotes the effective application of building comfort systems. For that reason, we regularly publish educational materials, such as this one, to share information gathered from laboratory research, testing programs, and practical experience.

This publication focuses on central geothermal systems that use borefields for their ground source. This manual discusses system design considerations and options, piping, airside considerations, and system operation and control.

We encourage engineering professionals who design building comfort systems to become familiar with the contents of this manual and to use it as a reference. Architects, building owners, equipment operators, and technicians may also find this publication of interest because it addresses system layout and control.

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Introduction to Geothermal Systems

A growing number of building owners are favoring geothermal HVAC systems to achieve premium efficiency without the use of boilers for heating. Premium efficiency is achieved by using moderate earth temperatures as the heat sink and heat source instead of the wider range of ambient air temperatures. Gas boilers can be eliminated by using heat pump chillers that provide both cooling and heating capability.

Geothermal systems are used for a wide range of building types, from 2 ton (7 kW) residential units to 10,000 ton (35,170 kW) central plants. These systems may include distributed heat pumps installed in zones, or a central plant design with hydronic distribution.

The use of central geothermal systems has gained popularity in the last decade, and heat pump manufacturers have released new equipment that offers new design options for central geothermal systems. Five configurations have emerged as the most commonly used central geothermal systems. This Applications Engineering Manual describes the five base system types and provides criteria to help designers select the right system for each project.

Central Geothermal vs. Distributed

Both distributed and central geothermal systems offer unique benefits beyond their geothermal efficiency. [Table 1](#) provides a comparison of system characteristics for distributed heat pump and central geothermal systems for consideration by the system designer and building owner.

Table 1. Distributed and central geothermal system comparison

Characteristic	Distributed	Central
Number of heat pumps	Many	Few
Heat pump enabling technology	Water-Source Heat Pump terminal units	Heat pump chillers
Location of heat pumps	In each space	Central mechanical space
Method of conditioning the space	Water-Source Heat Pump terminal units	Central air handlers and VAV boxes and/or fan coil terminal units
Number of hydronic loops	One (ground loop)	Changeover systems have two loops (ground loop and distribution loop) Heating/cooling systems have three loops (ground loop, heating loop, and cooling loop)

For more information on distributed geothermal systems, refer to the Trane Applications Engineering Manual SYS-APG010-EN *Water-Source and Ground-Source Heat Pump Systems*.

A central system is typically viewed as having the following advantages when compared to the distributed system:

- **Maintenance:** A central system uses fewer compressor and fan bearing pieces of equipment and therefore will have reduced maintenance. Also, maintenance of central refrigeration and air-handling systems takes place away from occupied spaces, reducing the impact on building users.
Centralized air handling also eliminates the need for unit drain pans and filters within occupied areas. This simplifies maintenance and cleaning, but also allows for more flexibility in air-handling configurations and options.
- **Acoustics:** Central systems using both chillers and air handlers have many options available for sound attenuation. In addition, locating the HVAC unit sound sources away from the space may have an immediate benefit to space acoustics.
- **Air economizer:** Central air handlers with integrated airside economizers can be intelligently controlled to change the amount of heat rejected to the ground loop. This can be used to maximize system efficiency or manage seasonal changes in ground temperature.
- **Air filtration flexibility:** Central air handlers can be equipped with a wide range of high-efficiency filtration and condensate management options to improve indoor air quality (IAQ). Many of these filtration options are not available for distributed water-source heat pump terminal units.

Geothermal Heat Pumps

Central geothermal systems use water-to-water heat pumps (WWHP) to transfer heat between the ground loop and a hydronic distribution loop(s). Since geothermal heat pump technology has evolved in recent years, the following definitions are needed for clarity. Additional terminology related to heat pumps and geothermal systems can be found in the appendix.

- **Water-to-Water Heat Pump (WWHP):** A unit that regulates a heating or cooling temperature by transferring heat between two fluid sources. It may or may not include a reversing valve to change the roles of the heat exchanger.
- **Modular heat pump:** A heat pump consisting of multiple modules that function together as a bank. Each module includes an independent refrigerant circuit. In some cases, a single module can be used.
- **Modular multi-pipe heat pump:** A cooling and/or heating unit typically consisting of three or more refrigeration modules and accessory modules assembled together to create a multi-pipe bank. Modular multi-pipe units are normally characterized by their field-assembled nature whereby individual modules are shipped separately to the job site and assembled together with integral interconnecting valves, piping, and controls with a single power connection to create the complete modular multi-pipe unit.
- **Packaged heat pump:** A factory-assembled heat pump operating in a standalone manner—typically lower in cost and available in higher capacity compared to modular heat pumps.

Types of Central Geothermal Systems

Two primary factors influence which central geothermal system type is best suited for a project: the heating and cooling system type, and the system capacity. Of course, project cost will also be an important consideration!

Heating and Cooling System Type

- **Two-pipe changeover systems** operate in heating mode **or** cooling mode. Changeover between modes may be achieved with refrigerant reversing (valves in the heat pumps) or hydronic reversing (valves in the hydronic system).
- **Four-pipe systems** can operate in simultaneous heating **and** cooling mode with separate heating and cooling distribution loops. The central plant must be capable of simultaneous production of heating and cooling capacity.

System Capacity

- **Systems < 100 tons (352 kW)** may be too small for packaged heat pumps. Designers should consider modular heat pumps with smaller increments of capacity.
- **Systems that are 100 tons to 300 tons (352 kW to 1,055 kW)** may be designed around modular or packaged heat pumps. Modular heat pumps simplify the system control by integrating some control functions into the heat pump equipment controller. Packaged heat pumps typically offer lower equipment cost and higher system capacity.
- **Systems > 300 tons (1,055 kW)** are likely to require multiple packaged heat pumps or multiple banks of modular heat pumps. Additional valves, pumps, and controls are needed in the system to coordinate operation of multiple heat pumps.

Introduction to Geothermal Systems

Table 2 and Figure 1 provide high-level comparison of the five base configurations outlined in this manual. Additional details for each system type follow. Design engineers should refer to the dedicated chapter for each system type for information including component descriptions, system operation/control, and system alternatives.

Table 2. Comparison of the five base central geothermal systems

	Two-Pipe Changeover		Four-Pipe Heating and Cooling		
	Refrigerant Changeover Central Geothermal System	Hydronic Changeover Central Geothermal System	Modular Multi-pipe Central Geothermal System	Blended Loop Central Geothermal System	Parallel Central Geothermal System
Possible Design Range	20 Tons to 960 Tons ⁽¹⁾ (70 kW to 3,376 kW)	80 Tons to 10,000 Tons ⁺⁽²⁾⁽³⁾ (281 kW to 3,5170 kW+)	90 Tons to 600 Tons ⁽¹⁾ (317 kW to 2,110 kW)	80 Tons to 500 Tons ⁽²⁾ (281 kW to 1,759 kW)	240 Tons to 10,000 Tons ⁺⁽²⁾⁽³⁾ (844 kW to 35,170 kW+)
Typical Systems	< 200 Tons ⁽⁴⁾ (< 703 kW)	> 100 Tons (> 352 kW)	< 200 Tons ⁽⁴⁾ (< 703 kW)	100 Tons to 300 Tons (352 kW to 1,055 kW)	> 200 Tons (> 703 kW)
Heat Pump Type	Modular	Packaged	Modular Multi-pipe	Packaged	Packaged
Efficiency	Good ⁽⁵⁾	Good ⁽⁵⁾	Better ⁽⁵⁾	Better ⁽⁵⁾	Best ⁽⁵⁾
Controls Complexity	Low ⁽⁶⁾	Low ⁽⁶⁾	Med-Low ⁽⁶⁾	Med ⁽⁶⁾	Med-High ⁽⁶⁾

(1) Based on four-pipe modular WWHP with capacity 20 tons to 80 tons per module (70 kW to 281 kW per module), up to 12 modules and modular multi-pipe with capacity 30 tons to 60 tons (106 kW to 211 kW) per module, up to 10 modules (minimum of 3 modules).

(2) Based on screw compressor packaged heat pumps with capacity 80 tons to 250 tons (281 kW to 879 kW)—typical for geothermal. Up to two packaged heat pumps for blended loop geothermal systems.

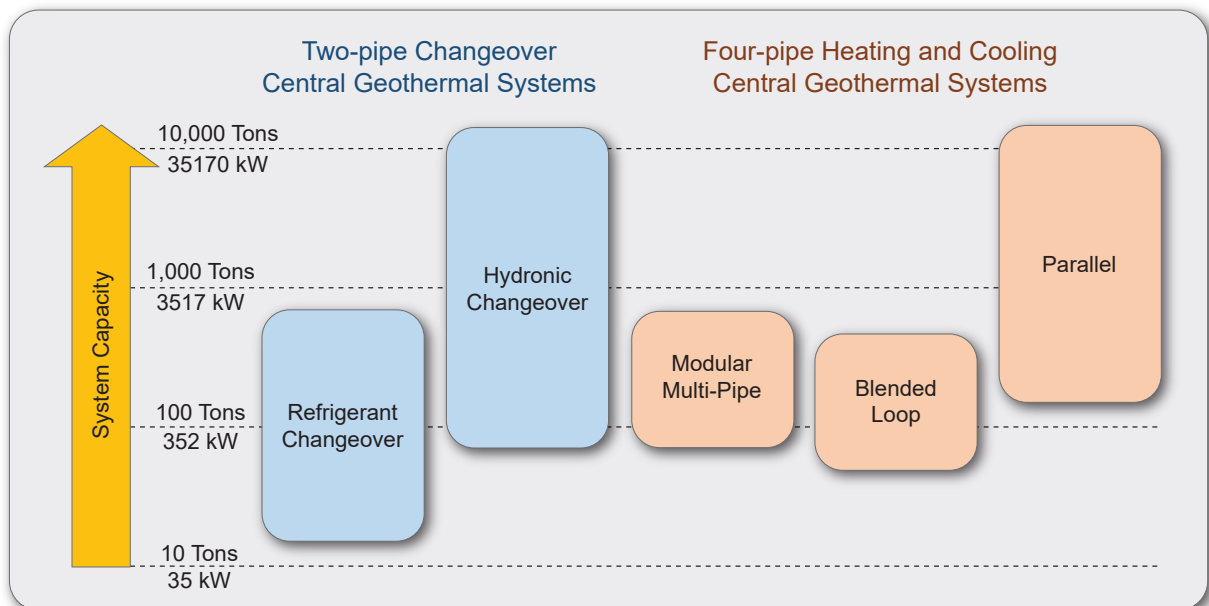
(3) Higher capacity central geothermal systems may include higher quantity of heat pumps or higher capacity heat pumps.

(4) Above 200 tons (703 kW), packaged heat pumps likely result in a lower system installed cost.

(5) Geothermal systems are a premium efficiency system. All system types are “Good” to start with. Modular multi-pipe and blended loop systems are marked “Better” due to built in heat recovery function. Parallel central geothermal is marked “Best” due to heat recovery function and ability to select higher efficiency heat pumps.

(6) Four-pipe systems have more controls complexity than two-pipe systems due to additional pumps and flow control logic. Of the three different four-pipe systems, the modular multi-pipe system is the simplest because more functionality is integrated into the heat pump controls. A parallel central geothermal system has more controls complexity due to heat pump and valve staging.

Figure 1. Capacity comparison of the central geothermal system types



Refrigerant Changeover Central Geothermal System

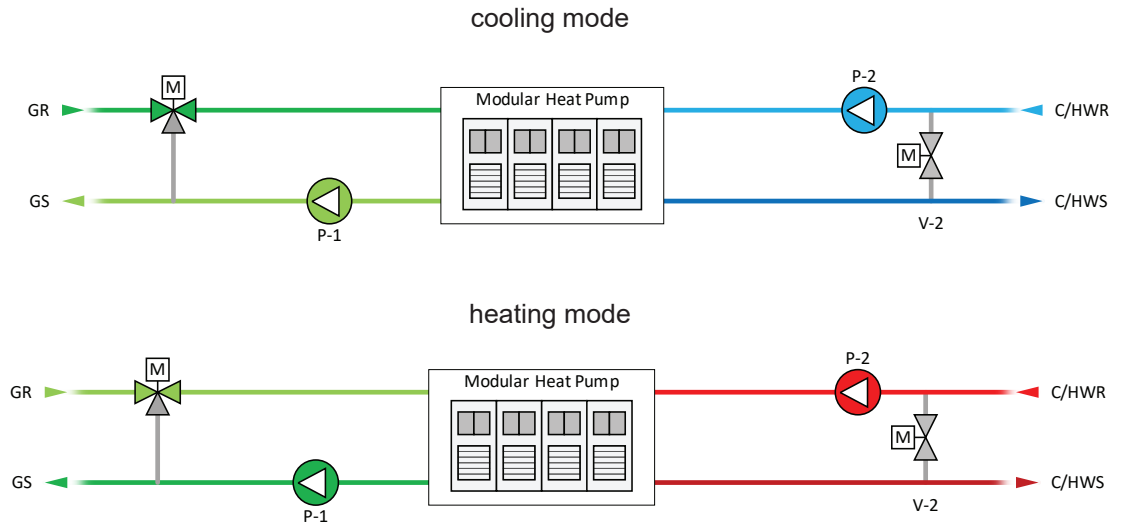
This system allows heating or cooling mode operation with the use of reversible refrigeration cycle water-to-water heat pumps (Figure 2). The reversing valves, actuators, and control logic are built into the heat pump. The system controller or Building Automation System (BAS) determines the need for heating or cooling and enables the heat pump with an operating mode and setpoint temperature (Table 3).

Fluid in the ground loop and distribution loop is isolated from each other and only connect thermally through the refrigerant circuit.

Table 3. Advantages and considerations for refrigerant changeover central geothermal systems

Advantages	Considerations
<ul style="list-style-type: none"> Reversing function is built into heat pumps Piping layout and system controls are simple Fluid in the ground loop and distribution loop is isolated 	<ul style="list-style-type: none"> System does not provide simultaneous heating and cooling Airside heat recovery for ventilation is recommended or possibly required by code Energy may be wasted when changing between cooling and heating modes

Figure 2. Refrigerant changeover central geothermal system



Hydronic Changeover Central Geothermal System

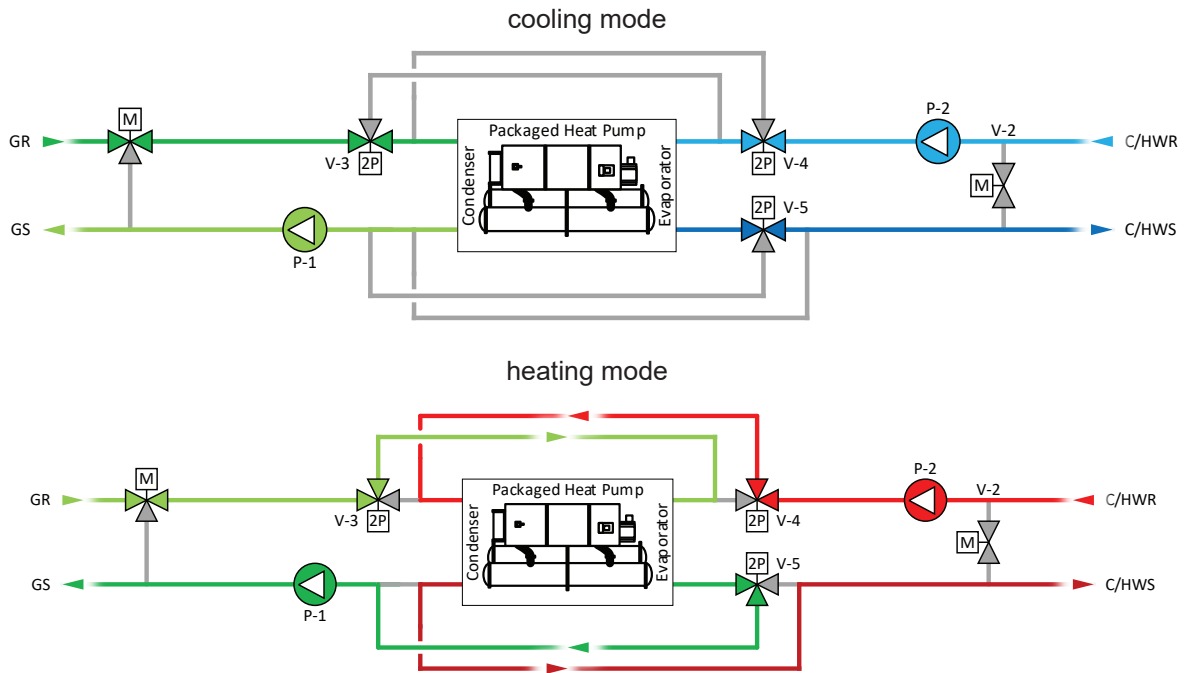
This system allows heating or cooling mode operation with the use of hydronic changeover valves, enabling designers to select non-reversible, packaged heat pumps (Figure 3). Packaged heat pumps are typically available at lower cost and higher capacity than modular heat pumps. Hydronic changeover central geothermal systems may be scaled to very high capacity (Table 4).

The system controller or BAS determines the need for heating or cooling, positions the hydronic changeover valves for the correct mode, then enables the heat pump with an operating mode and setpoint temperature.

Table 4. Advantages and considerations for hydronic changeover central geothermal systems

Advantages	Considerations
<ul style="list-style-type: none"> Non-reversible, packaged heat pumps may be used with lower cost and higher capacity compared to modular heat pumps System is scalable to very high capacity 	<ul style="list-style-type: none"> Reversing function requires additional valves and controls Airside heat recovery for ventilation is recommended or possibly required by code Fluids in the ground loop and distribution loop mix during system changeover unless an isolation heat exchanger is added Energy may be wasted when changing between cooling and heating modes

Figure 3. Hydronic changeover central geothermal system



Modular Multi-pipe Central Geothermal System

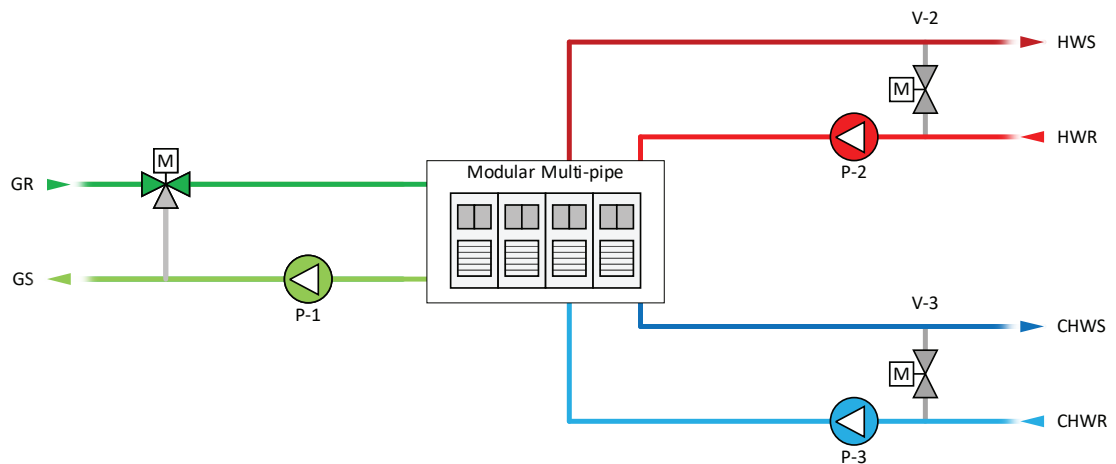
This system is designed around modular multi-pipe heat pumps, which are intended to simplify the system design by incorporating more functionality into the heat pump itself. Modular multi-pipe heat pumps (Figure 4) simultaneously control the cooling and heating supply temperatures by changing the operating mode of individual modules in the heat pump bank.

Fluids in the ground loop, cooling loop, and heating loop are isolated from each other and only connect thermally through the refrigerant circuit (Table 5).

Table 5. Advantages and considerations for modular multi-pipe central geothermal systems

Advantages	Considerations
<ul style="list-style-type: none"> Reversing function and compressor staging control is built into heat pump bank controller Heat recovery function improves system efficiency when simultaneous heating and cooling loads exist Fluids in the ground loop and distribution loops are isolated 	<ul style="list-style-type: none"> Modular multi-pipe heat pumps are more expensive than packaged heat pumps Temperature regulation may be less precise than packaged heat pumps

Figure 4. Modular multi-pipe central geothermal systems



Blended Loop Central Geothermal System

This system allows simultaneous heating and cooling mode operation with control of both heating and cooling loop supply temperatures. Packaged, non-reversible heat pumps are connected in a heat recovery manner (between the cooling loop and heating loop), with the ground loop used to balance loading between evaporator and condenser.

When simultaneous loads exist, the heat pump regulates the larger (dominant) load, while the BAS or system controller regulates the smaller (non-dominant) load by modulating ground loop flow. Some refer to this as false loading the non-dominant loop.

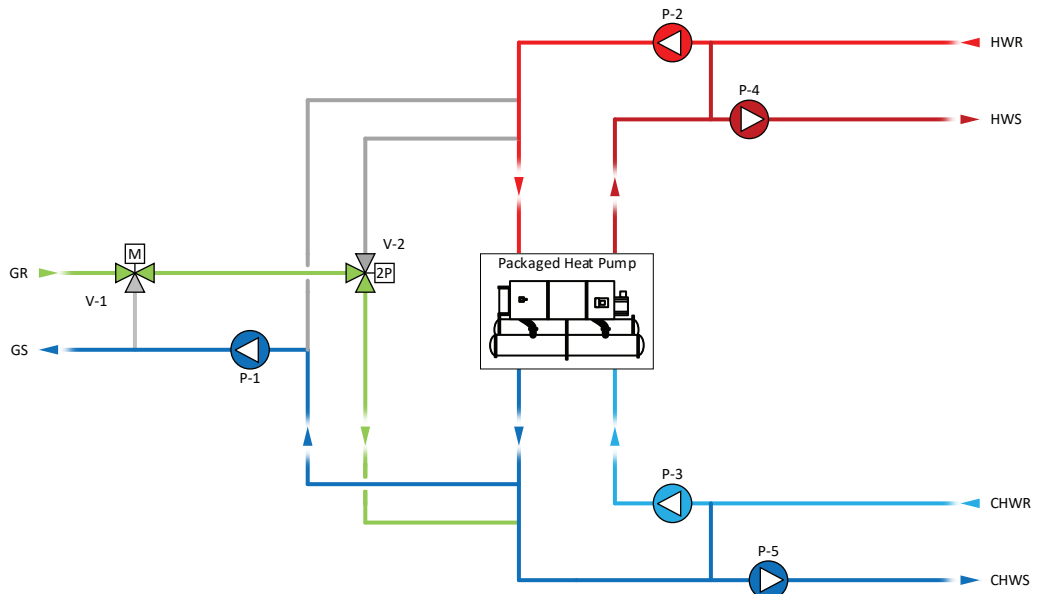
The blended loop central geothermal system (Figure 5) is intended as a simple, low-cost option for buildings that can be served by one or two packaged heat pumps. Buildings that require three or more packaged heat pumps should consider the parallel central geothermal system.

The design of this system results in fluid mixing between the ground loop, cooling loop, and heating loop. Isolation heat exchanger(s) may be added to the system to prevent mixing of fluids. See Table 6 for advantages and considerations for this system.

Table 6. Advantages and considerations for blended loop central geothermal system

Advantages	Considerations
<ul style="list-style-type: none"> • Packaged heat pumps provide lower equipment cost compared to modular multi-pipe heat pumps • Heat recovery function improves system efficiency when simultaneous heating and cooling loads exist 	<ul style="list-style-type: none"> • Heat pumps operate at full compressor lift (heating temperature minus cooling temperature) whenever simultaneous loads exist • Fluids in the ground loop, cooling loop, and heating loop mix

Figure 5. Blended loop central geothermal system



Parallel Central Geothermal System

This system uses multiple non-reversible heat pumps, connected in a parallel arrangement. Each heat pump can operate in cooling mode, heating mode, or heat recovery mode, depending on the position of valves in the system. Parallel central geothermal systems are highly efficient due to the built-in heat recovery function and the ability to stage heat pumps for optimal efficiency (Figure 6).

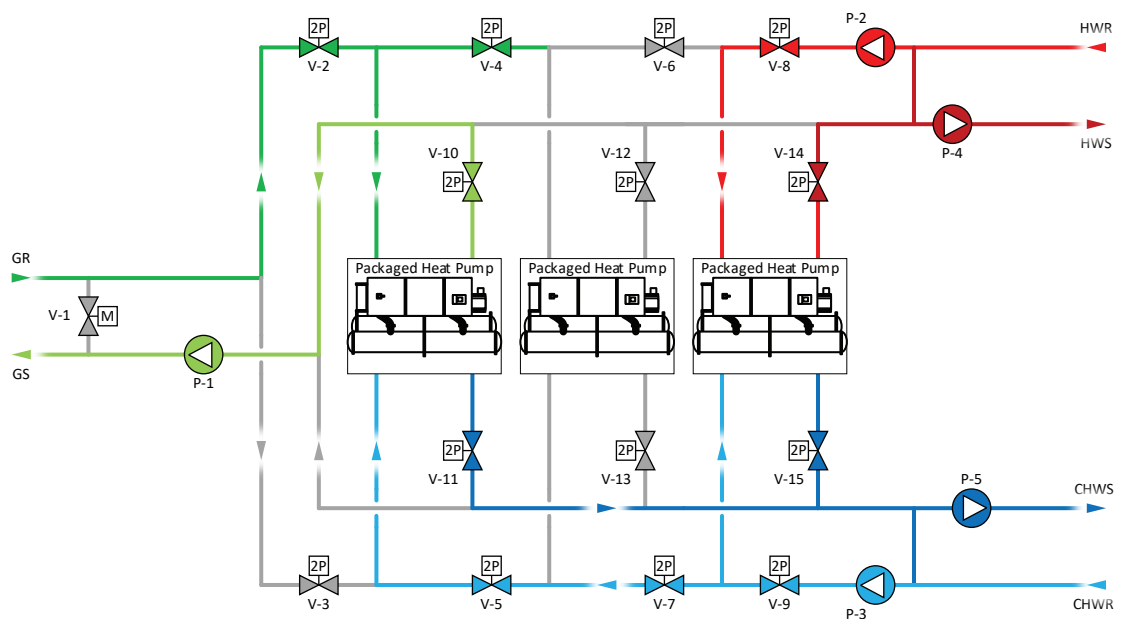
The BAS or system control must coordinate valve position and pump control, depending on the operating mode of each heat pump in the system.

The parallel central geothermal system is easily scalable with more heat pumps operating in parallel. See Table 7 advantages and considerations for this system.

Table 7. Advantages and considerations for parallel central geothermal systems

Advantages	Considerations
<ul style="list-style-type: none"> System is scalable to very high capacity Heat recovery function improves system efficiency when simultaneous heating and cooling loads exist Heat pump staging allows optimal system efficiency by reducing compressor lift for heat pumps not operating in simultaneous heating and cooling mode 	<ul style="list-style-type: none"> System controls require more valve and pump logic than other geothermal system types Fluids in the ground loop, cooling loop, and heating loop mix

Figure 6. Parallel central geothermal system

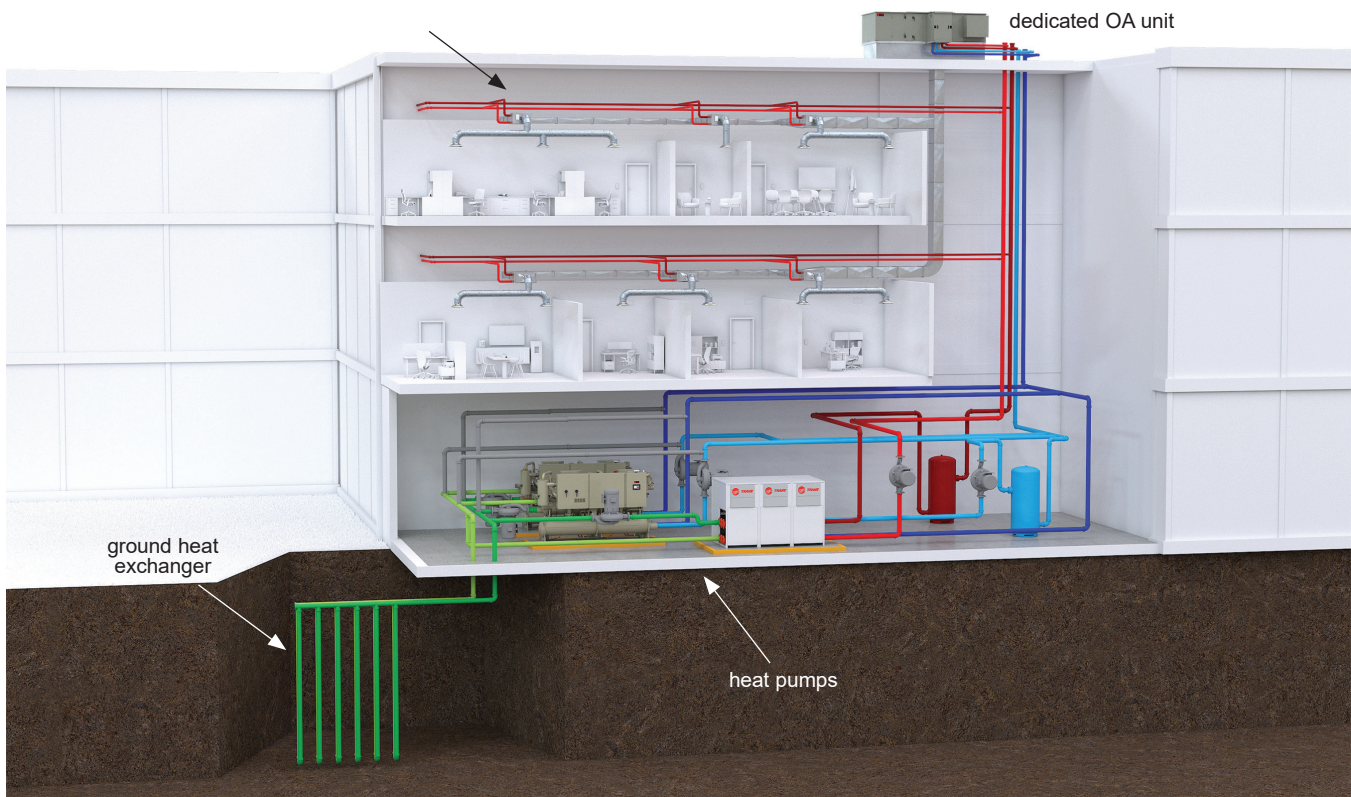


Geothermal System Design Considerations

Ground-Coupled Heat Pump (GCHP) Borefield Construction

A ground-coupled heat pump (GCHP) system uses a closed system of special, high-density polyethylene pipes that are buried in the ground at a depth that takes advantage of the earth's relatively constant temperature, using the ground as the heat rejecter and heat adder (Figure 7).

Figure 7. Ground-coupled heat pump system



Most GCHP systems do not actually get rid of heat, they store it in the ground for use at a different time. During the cooling season, heat rejected by the heat pumps causes the loop temperature to increase. As the fluid flows through the buried pipes, heat is transferred from the warm fluid to the cooler ground. In a sense, the heat is stored in the earth for use at a later time. Conversely, during the heating season, heat extracted by the heat pumps causes the loop temperature to decrease. The cool fluid flowing through the buried pipes extracts the stored heat from warmer ground.

GCHP systems offer the potential for reduced energy use when compared to a traditional boiler/tower system because they can reduce (or eliminate) the energy needed to operate a cooling tower and/or boiler. Eliminating the cooling tower and boiler also has architectural and maintenance advantages, and may free up floor space in the building. In addition, by removing the need for a

boiler, a GCHP system reduces (or eliminates) on-site fossil fuel use, helping the building achieve decarbonization goals. Finally, the loop may operate at cooler temperatures during the cooling season than in a conventional boiler/tower system. This results in the heat pump compressors operating more efficiently.

The installation costs associated with this system, however, must be considered to determine the economic viability. In general, the largest portion of the installation cost is due to the ground heat exchanger. Installation requires excavation, trenching, or boring, and in some locales there may be few qualified contractors for installing the ground heat exchanger.

In a perfectly balanced system, the amount of heat rejected to the ground over the year would equal the amount of heat extracted, eliminating the need for a cooling tower and boiler. In most applications, however, there is an imbalance between heat rejected to the ground and heat extracted. This imbalance requires the ground heat exchanger to be larger to prevent the ground temperature from changing over time.

While eliminating both the cooling tower and boiler likely results in the greatest overall energy savings, for many applications it requires a larger (and more expensive) ground heat exchanger. Adding a small cooling tower to the loop for a cooling-dominated application, or adding a small boiler for a heating-dominated application, can reduce the size of the ground heat exchanger, making a GCHP system more economically feasible.

Ground Heat Exchanger Configurations

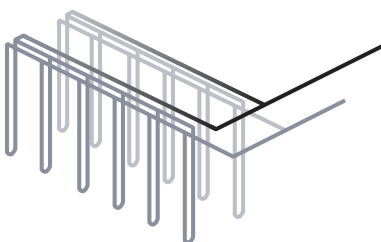
The pipes that make up the ground heat exchanger are typically oriented in either a vertical, horizontal, or spiral pattern. Any of these patterns can be designed to provide the same fluid temperatures under a given set of conditions. The choice depends on available land, soil conditions, and excavation costs.

Vertical Loops

Vertical loops are the most common in commercial applications due to the limited land that is generally available to bury the heat exchanger (Figure 8). Vertical boreholes—with a diameter of 4 in to 6 in (10 m to 15 cm) each—are drilled to depths of 200 ft to 500 ft (60 m to 150 m), typically about 10 ft to 20 ft (3 m to 6 m) apart. A closed piping loop (two pipes with a U-bend at the bottom) is inserted into each borehole, after which the hole is filled with grout and backfilled. The grout seals the bore to prevent surface contaminations from getting into the ground or aquifer, and transfers heat from loops to the ground. High-performance grouts are available with additives to improve thermal conductivity.

The HVAC design engineer should be familiar with federal, state, and local codes for drilling of water wells or boreholes for ground-coupled systems, since there can be differences. Some contractors have **low-profile drilling rigs** that can be used in a basement. Or **directional drilling** equipment can allow a large number of bores to be drilled from within a smaller surface footprint, from which they then fan out underground.

Figure 8. Vertical ground heat exchanger



Advantages of vertical loops include:

- They typically require the least amount of land of the three configurations. Vertical loops typically require anywhere from 60 ft² to 275 ft² of ground surface per “block” cooling ton (1.6 m²/kW to 7.3 m²/kW).
- They typically require less total piping than the other two configurations because the ground temperature is more constant at greater depths.
- When piped in a parallel reverse-return configuration, this pattern typically requires the least amount of pumping energy of the three configurations.

Drawbacks include:

- Drilling costs are frequently higher than the trenching costs associated with horizontal or spiral loops.
- Grouting and backfilling of the boreholes require special attention to fill material and to ensuring that the pipes and surrounding earth remain in contact.
- If the boreholes are spaced too close together, there is a potential for long-term heat build-up in the ground that may be undesirable for a cooling-dominated application.
- Installation requires the knowledge and availability of a certified loop contractor with proper drilling equipment.

Horizontal Loops

Horizontal loops are often considered when adequate land is available (Figure 9). Historically, horizontal loops often consisted of a single layer of pipe buried in the ground using a trenching machine. However, land requirements have been reduced with the advent of multiple-layer horizontal loops. While less land and trenching is required, a multiple-layer loop requires more total length of piping than a single-layer loop.

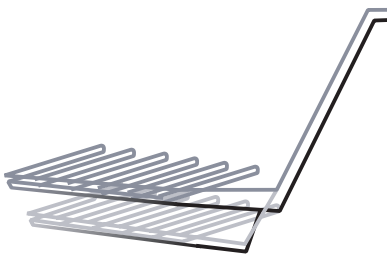
Each closed-loop pipe is placed in a trench, which is typically 6 ft (1.8 m) deep and spaced 6 ft to 15 ft (1.8 m to 4.6 m) apart. Trench length can range from 100 ft to 400 ft per “block” cooling ton (8.7 m/kW to 34.7 m/kW) for a single-layer loop.

One option to reduce excavation needed is to use **directional drilling** equipment, in which the drilling head can be steered up and down and side to side, achieving precision placement. This may allow the horizontal loops to be installed under a parking lot or an athletic field while that space is still in use. Loops can be layered at different depths and routed to a precise location, such as an equipment room wall or underground access vault.

Advantages of horizontal loops include:

- Trenching costs are typically lower than the drilling costs associated with vertical loop installation.
- In cooler climates, horizontal loops may not build up as much heat over time as vertical loops, because the pipes are closer to the surface and heat can be dissipated to the atmosphere.

Figure 9. Horizontal ground heat exchanger

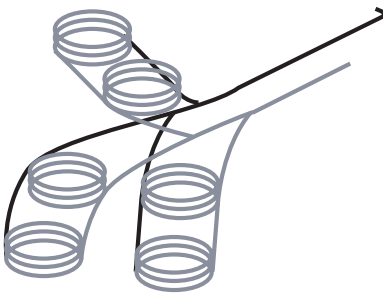


Drawbacks include:

- Horizontal loops require a larger area of land than vertical loops. The excavation process can be disruptive in that the land cannot be used for other purposes at the time.
- At this shallower depth, ground temperatures are subject to seasonal temperature variations, rainfall, and snow melting. Obtaining the same loop temperatures as a vertical loop requires a more complicated design with longer pipe lengths.
- The longer pipe lengths also require more antifreeze solution (when necessary) and more pumping energy than vertical loops.
- The pipe is at greater risk of damage during backfilling of the trenches.

Spiral Loops

Figure 10. Spiral ground heat exchanger



A variation of the multiple-layer, horizontal loop is the spiral loop (Figure 10). The spiral loop includes a roll of pipe that is unraveled into circular loops, tied together, and then placed either vertically in a trench or horizontally in an open pit.

The spiral loop generally requires more total piping—typically between 500 ft and 1000 ft per “block” cooling ton (43 m/kW to 86 m/kW)—but less trenching than multiple-layer, horizontal loops. Both horizontal and spiral loop systems are generally associated with small commercial or residential buildings where land requirements are less of a factor.

Advantages of spiral loops include:

- Less land area, and less trenching, is typically required for spiral loops than for traditional horizontal loops.
- Installation costs are typically lower than for traditional horizontal loops, because less trenching is required.
- Trenching costs are typically lower than the drilling costs associated with vertical loop installation.
- Spiral loops may not build up as much heat over time as vertical loops, because the pipes are closer to the surface, where heat can be dissipated to the atmosphere.

Drawbacks include:

- Spiral loops require a larger area of land than vertical loops.
- Spiral loops require more total length of piping than either vertical or horizontal loops, which increases pump energy use.
- At the shallower depth, ground temperatures are subject to seasonal temperature variations, rainfall, and snow melting. Obtaining the same loop temperatures as a vertical loop requires a more complicated design with longer pipe lengths.
- The longer pipe lengths also require more antifreeze solution (when necessary) than vertical loops.
- The pipe is at greater risk of damage during backfilling of the trenches.

Ground heat exchangers should be designed by a certified professional:

- Certified Geo-Exchange Designer (CGD)
- GSHP Commercial System Designer (GCSD)

A **directory of certified professionals** is available on the International Ground Source Heat Pump Association (IGSHPA) web site:

www.igshpa.org/business-directory

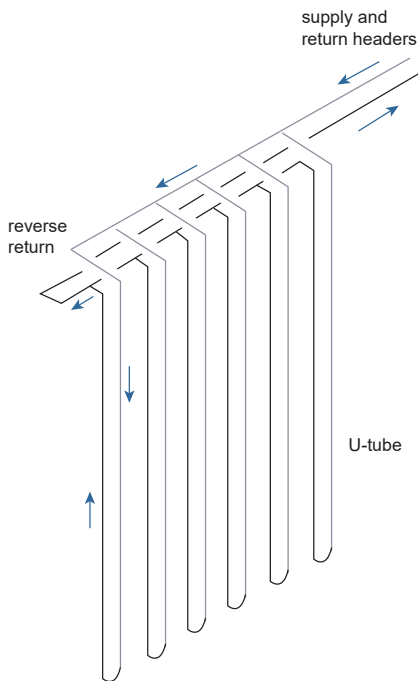
Design of the Ground Heat Exchanger

The ground heat exchanger must be sized to maintain the loop temperature within the minimum and maximum limits for which the heat pumps have been selected. And it must be sized to maintain those temperatures over the expected life of the system. If the heat exchanger is too small, the ground temperature may increase over time, degrading the performance of the system.

This section focuses primarily on vertical, closed-loop ground heat exchangers. Due to limited land availability, this is the most common type of ground heat exchanger used in commercial or institutional buildings.

The primary components of the vertical ground heat exchanger include (Figure 11):

Figure 11. Components of a vertical ground heat exchanger

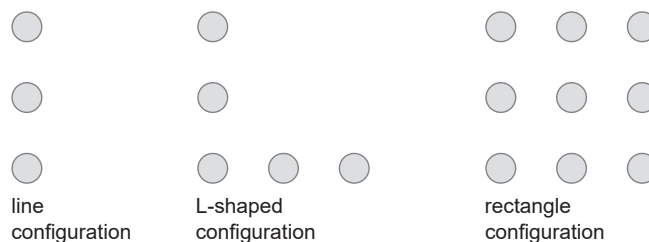


- **Supply and return headers.** Pipes used to convey the total system flow from the loop inside the building to the individual, parallel U-tubes. Headers are typically constructed of larger-diameter pipe to minimize pressure drop, and are typically installed in a reverse-return configuration to better equalize pressure drops and balance flows through the individual U-tubes.
- **U-tubes.** Pipes that convey fluid from the supply header, down into a borehole (or trench), and then returned back up the same borehole (or trench) to the return header. The pipe includes a 180-degree fitting, or U-bend, at the bottom of a borehole (or at the end of a trench). The heat exchanger typically consists of multiple U-tubes connected to the supply and return headers. The U-tubes are typically installed in a parallel configuration so that only a portion of the total system flow rate travels through a single U-tube, minimizing overall pressure drop.
- **Grout.** After the U-tube is inserted, the hole is filled with grout. This seals the bore to prevent surface contaminations from getting into the ground or aquifer. High-performance grouts are available with additives to improve thermal conductivity and increase heat transfer between the U-tube and the ground.

The piping used for the ground heat exchanger is typically high-density polyethylene (HDPE) with thermally fused joints. Pipe diameter for the U-tubes ranges from 0.75 in to 1.25 in (20 mm to 60 mm), depending on the diameter of the borehole.

A borefield is typically laid out to ensure proper separation of the individual U-tubes. Common configurations include arranging the boreholes in a straight line, L-shaped pattern, or rectangle (Figure 12), but other configurations are possible.

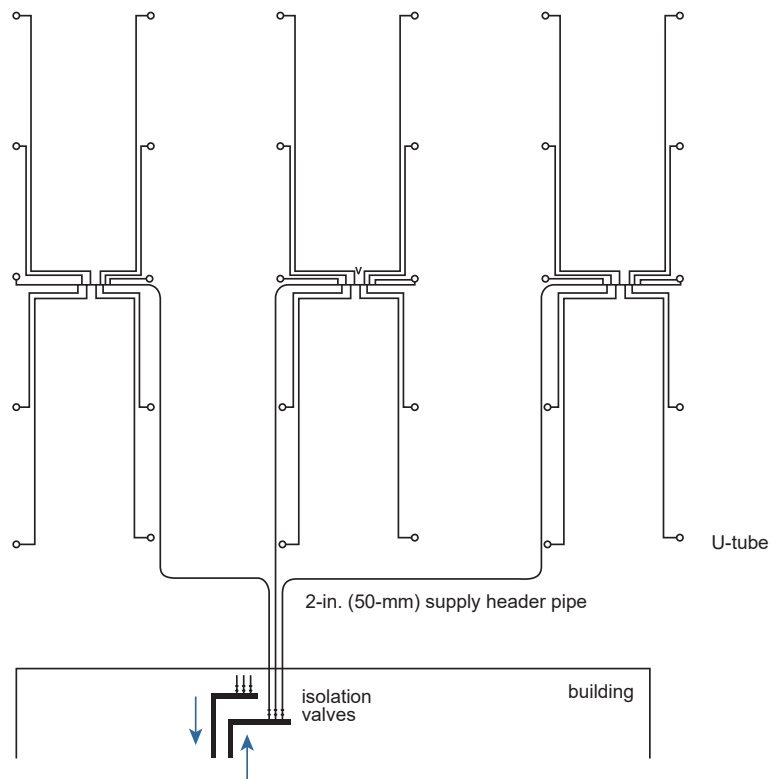
Figure 12. Examples of vertical heat exchanger configurations



It is typically recommended to group 10 to 12 U-tubes on a single header, and isolate each group with valves (Figure 13). This allows for easier flushing of the U-tubes to purge air and debris after installation. And if a leak occurs, the affected section of the borefield can be shut off to fix the leak, while the remaining sections of the field remain in operation.

The final benefit of this approach is simpler installation. Smaller header pipes can often be purchased in a roll, which simplifies installation by greatly reducing the number of field-fabricated, thermally-fused joints. In contrast, larger pipe sizes usually need to be purchased in straight sections, increasing the number of joints fabricated in the field.

Figure 13. Example layout of well field (only supply-side piping shown)



Source: *Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*, Figure 5.6 © American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., www.ashrae.org

As an example, a 2 in. (50 mm) HDPE (SDR 11) header pipe will convey 30 gpm (1.892 L/s) at an acceptable pressure drop—approximately 2.3 ft of H₂O per 100 ft of piping (0.23 kPa/m). For a 30 ton (106 kW) system, with a total system flow rate of 90 gpm (5.678 L/s), dividing the U-bends into three separate groups allows each group to be served by a 2 in. (50 mm) header pipe (Figure 13).

Some design engineers or contractors prefer to locate the isolation valves inside the building, routing the separate header pipes from that location to each group of U-tubes in the borefield (as shown in Figure 13). Others prefer to locate the isolation valves in a vault (or pit) that is located near the borefield, and then install a single, larger set of pipes from this vault to connect to the building loop.

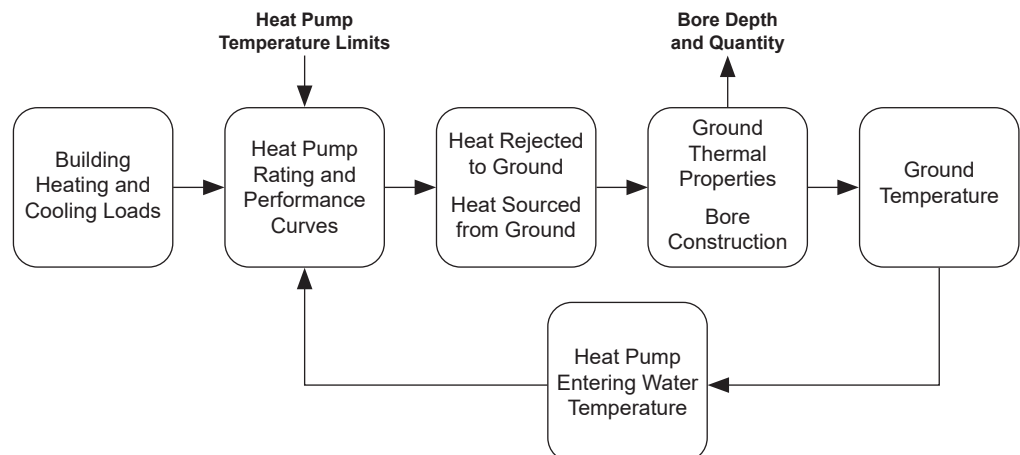
Borefield Sizing

Ground-Coupled Heat Pump (GCHP) systems use a ground heat exchanger, or “borefield,” as the heat sink and heat source for the system. This is the costliest part of a geothermal system. Ground heat exchanger sizing requires many assumptions, posing a risk that some assumptions are wrong. If the borefield size is too large, the project budget may not be approved. On the other hand, if the borefield size is too small, system performance is likely to be impacted. Proper borefield sizing requires special software capable of modeling the thermal characteristics of the earth and the material properties of the bore. Borefield sizing should be done by a certified professional, such as a Certified Geo-Exchange Designer (CGD) or a GSHP Commercial System Designer (GCSD). A directory of certified professionals is available on the International Ground-Source Heat Pump Association (IGSHPA) website (www.igshpa.org/business-directory).

The process of sizing a borefield may include the following steps (Figure 14):

1. Calculate the hourly heating and cooling loads with energy modeling software, such as Trane TRACE™.
2. Estimate the heat pump ratings and performance. The most important factor for this step is the heat pump operating temperature since it has a direct impact on heat pump performance (compressor lift).
3. Calculate heat rejected to and sourced from the ground, including the heat of compression from the heat pumps.
4. Use ground loop modeling software to estimate the operating temperature of the ground heat exchanger, given the heat load values and bore construction specifications. The ground loop software calculates the depth and quantity of bores needed to keep heat pump entering fluid temperature within the specified range. The ground loop software also considers year over year temperature drift for a target design life. A 20-year design window is often used.
5. Borefield sizing may require multiple iterations to find the optimal balance between bore depth, bore count, bore materials, and heat pump selections.

Figure 14. Borefield sizing workflow



Thermal Conductivity Testing

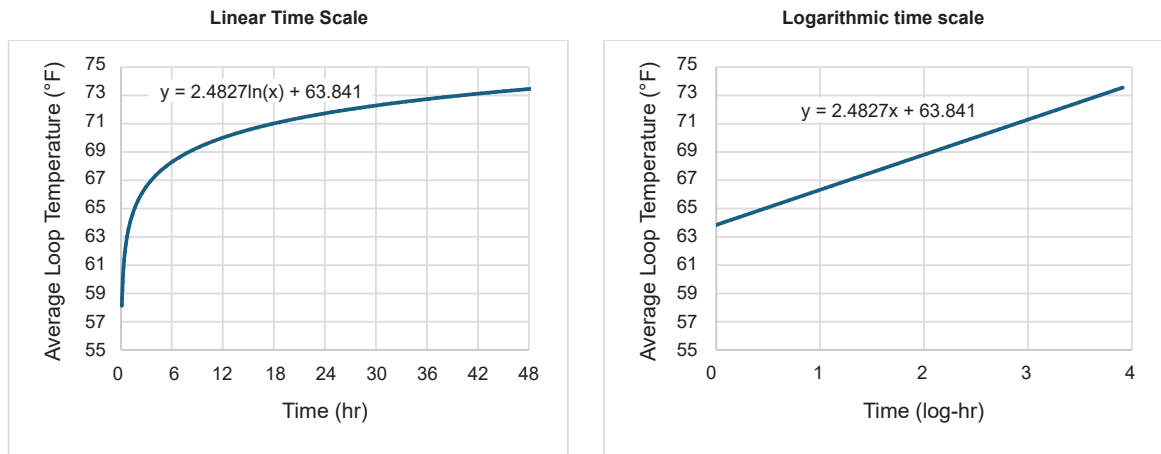
Thermal conductivity testing is used to verify that the ground heat exchanger design can deliver the expected thermal performance. Specifically, this testing confirms the assumptions made when sizing the borefield. Thermal conductivity testing improves the likelihood of success for the project and the long-term operation of the system.

The test is conducted on-site with a complete borehole constructed to the specified dimensions and materials. The test protocol consists of pumping fluid through the bore, applying a constant heat load, and monitoring fluid temperature into and out of the bore. High values of thermal conductivity means that the ground experiences less temperature rise for a given amount of heat rejection.

The thermal conductivity temperature rise has a logarithmic profile. ASHRAE Research Project 1118, titled "Methods for Determining Soil and Rock Formation Thermal Properties from Field Tests," provides mathematical formulas for the temperature rise profile. The formula includes bore depth, heat load value, and a factor of 4π .

$$\text{Thermal Conductivity} = \frac{3.412 * \text{HeatLoad}(W)}{4\pi * \text{BoreDepth}(ft) * \text{TempRiseSlope}(\text{°F}/\ln(\text{hr}))}$$

Figure 15. Temperature rise during thermal conductivity test



For the example above (Figure 15), the heat load value is 8892 Btu/h (2606 W) and the bore depth is 244 ft (74.37 m). The temperature rise slope is 2.4827 °F/hr. (logarithmic hours) (-16.4 °C/hr).

$$\text{Thermal Conductivity} = \frac{3.412 * 2606W}{4\pi * 244ft * 2.4827\text{°F}/\ln(\text{hr})} = 1.17 \frac{\text{Btu}}{\text{hr ft °F}}$$

General Recommendations for Designing Ground Heat Exchangers

Other publications contain more complete details related to designing the ground heat exchanger, but the following are some general recommendations:

For more information on the design and layout of ground heat exchangers, refer to Chapter 35, "Ground-Source Heat Pumps and Geothermal Energy," in the 2023 ASHRAE Handbook—*HVAC Applications* (www.ashrae.org); the ASHRAE manual, *Geothermal Heating and Cooling: Design of Ground-Source Heat Pump Systems*; and the International Ground-Source Heat Pump Association (IGSHPA) manual, *Closed-Loop, Ground-Source Heat Pump Systems: Installation Guide*.

- *Drill a test borehole and perform a thermal conductivity test prior to finalizing system design.*

As mentioned previously, this helps determine the actual soil thermal properties, as well as drilling (or trenching) conditions, at the site.

- *Size the ground heat exchanger based on the "block" cooling and heating loads, rather than summing installed heat pump capacities.*

In a system with multiple heat pumps, zone-by-zone load variation throughout the day—known as system load diversity—results in an instantaneous load that is less than summing the peak loads of all zones. Sizing the ground heat exchanger based on the "block" load typically results in a smaller heat exchanger.

- *Separate boreholes by at least 20 ft (6 m) to help avoid long-term changes in ground temperature.*

Spacing the boreholes further apart also allows for a reduced overall length of the heat exchanger, which can result in shallower, or fewer, boreholes.

- *Size boreholes with as small a diameter as possible and use a grout with high thermal conductivity.*

This minimizes the use of grout, which often has poorer thermal conductivity than the surrounding ground. When possible, use thermally enhanced grouts with higher thermal conductivity.

- *Design for a total system flow rate of 2.5 gpm to 3.0 gpm per ton of "block" cooling load (0.158 to 0.189 L/s per kW). Lower flow rate should be considered to reduce pump energy.*

Due to the pressure drop through the ground heat exchanger, excessive pump energy use can drastically reduce the energy-savings benefit of a ground-coupled system. To avoid over-pumping, the overall system flow rate should account for system load diversity and be based on the "block" load, rather than by summing installed heat pump capacities.

- *Minimize the use of antifreeze.*

Because the header piping and U-tubes are installed well below grade, the fluid inside the heat exchanger is not exposed to ambient temperature. The ground heat exchanger design software will typically estimate the minimum expected loop temperature, which would then indicate whether or not antifreeze should be added to the water inside the loop.

In many climates, ground heat exchangers for commercial or institutional buildings likely require little or no antifreeze because annual cooling loads are greater than annual heating loads, and because the quantity of heat rejected to the loop during the cooling mode is typically higher than the quantity of heat extracted from the loop during the heating mode.

- *Lay out piping and headers to simplify field fabrication and flushing.*

Beyond drilling boreholes or digging trenches, fabricating the heat exchanger at the project site involves fusing each U-tube to the header and connecting the header pipes to the building loop. This part of the project is labor-intensive and typically occurs in a deep trench. The use of pre-assembled headers and simple layouts can reduce installation cost and minimize risk. It is beneficial for the design engineer to consult with the drilling contractor to find ways to minimize labor cost and time.

- *Hire contractors that are experienced with the installation of ground heat exchangers.*

Experienced contractors have developed their own proven methods of installing U-tubes and headers. In addition, they likely have drilled or trenched in soil conditions similar to those of the project site.

System design variables can be changed to reduce the installed cost of a ground-coupled heat pump system (Table 8). However, these changes are not without side effects. Changing a system design variable often impacts energy use or some other aspect of system operation.

Table 8. Impact of various ground heat exchanger design decisions

System design variable	Impact on installed cost	Other impacts
Increase the upper temperature limit for fluid entering the geothermal heat pump during cooling mode	Reduces the required length of ground heat exchanger	Geothermal heat pump will be less efficient in cooling mode
Increase the lower temperature limit for fluid entering the geothermal heat pump during heating mode	Reduces the required length of ground heat exchanger	Geothermal heat pump will be less efficient in heating mode
Decrease diameter of U-tube piping	Reduces the cost of the ground heat exchanger and simplifies installation	Increases the required length of the ground heat exchanger
Increase the separation distance between boreholes	Reduces the required length of the ground heat exchanger	Increases the amount of land required and increases length of header piping
Install a cooling tower to supplement heat rejection ("hybrid" ground-coupled system)	Reduces the required length of the ground heat exchanger	Requires seasonal maintenance and operation of the cooling tower uses energy
Assume movement of groundwater in design of ground heat exchanger	Reduces the required length of the ground heat exchanger	Requires hydrological survey to confirm or risks under-performance of the heat exchanger

Source: *Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings, Table 4.12*
 © American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., www.ashrae.org

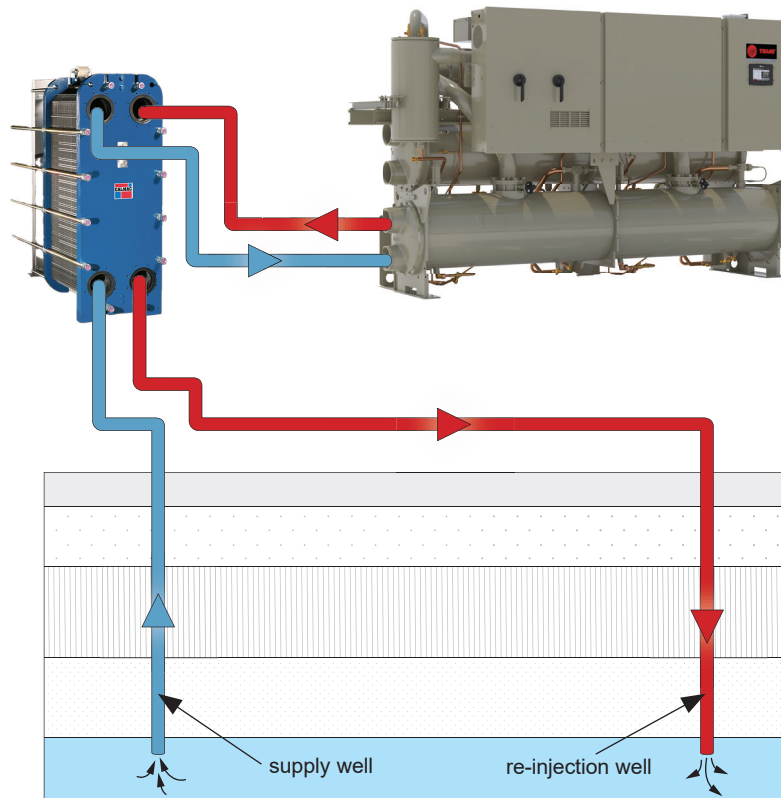
Ground-Water Heat Pump (GWHP) Well Construction

Open loop Ground-Water Heat Pumps (GWHP) use a supply well to pump water from an underground aquifer to use as a heat sink and heat source for the system. Water is returned to the aquifer with a re-injection well. GWHP capacity limits are based on the flow rate of water that can be achieved at the supply and re-injection wells. High capacity GWHP systems can be built with a relatively small number of wells, making them the most affordable geothermal option for most projects.

Note: *Groundwater-based geothermal systems may be subject to state or local regulations. Many locations require special permitting or site evaluations before installation. Once the system is installed and operational, annual usage reports may be required. Groundwater-based geothermal systems are not allowed in some locations. Be sure to understand local regulations before designing and installing a groundwater-based geothermal system.*

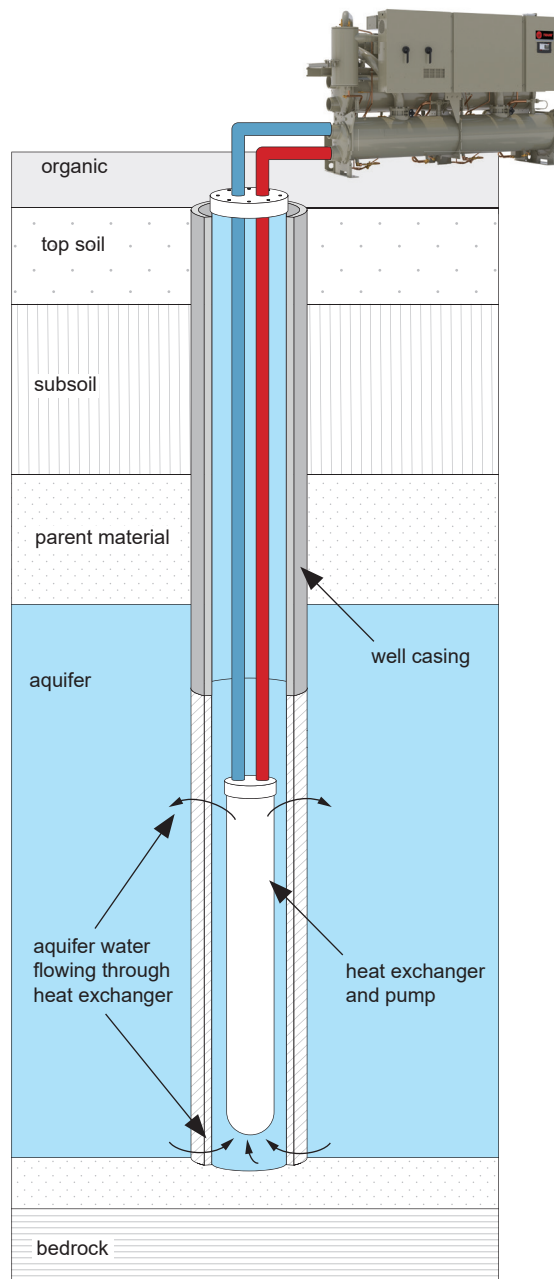
Intermediate heat exchangers are typically included in GWHP systems to isolate the heat pump working fluid from the aquifer water. Not only does this prevent contamination of the aquifer, but it also prevents sediment from the supply well from fouling heat pump heat exchangers. Dual heat exchangers allow one heat exchanger to be isolated for cleaning while the other remains in operation (Figure 16).

Figure 16. Open loop ground-water heat pump (supply and re-injection)



Closed loop GWHP systems utilize a ground-installed heat exchanger so that water does not need to be removed from the aquifer and re-injected. The heat exchanger facilitates heat transfer between the aquifer and the heat pump ground loop. A circulation pump actively moves aquifer water through the heat exchanger to maximize heat transfer. This technology aims to achieve performance similar to other groundwater geothermal systems without pulling water from the aquifer (Figure 17).

Figure 17. Closed loop ground-water heat pump (aquifer heat exchanger)



Heat Pump Selection for Geothermal Systems

Heat pumps in a geothermal system may operate in the following modes:

- **Heating mode:** Sourcing heat from the ground loop and adding heat to the heating loop.
- **Cooling mode:** Removing heat from the cooling loop and rejecting heat to the ground loop.
- **Simultaneous heating and cooling mode:** Removing heat from the cooling loop and adding heat to the heating loop. This is also known as heat recovery mode.

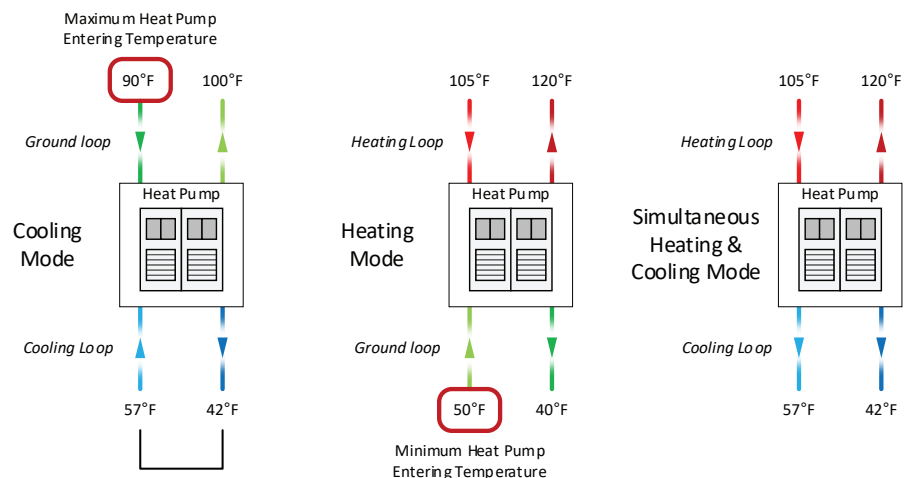
Designers must select heat pumps that can operate in each mode with the full range of ground loop temperatures, including seasonal changes. The warmest ground loop temperature typically occurs at the end of the cooling season, resulting from the accumulation of heat rejected by the heat pumps. Likewise, the coolest ground temperature typically occurs at the end of the heating season, resulting from the accumulation of heat sourced from the ground.

Many designers use the following criteria when selecting geothermal heat pumps:

- Cooling capacity is selected using the warmest ground temperature.
- Heating capacity is selected using the coolest ground temperature.
- Simultaneous heating and cooling capacity is selected at the design heating and cooling temperatures.

Figure 18 shows the different rating conditions that might be used when selecting geothermal heat pumps. It is common for either the heating condition or the simultaneous heating and cooling condition to be the limiting factor in heat pump selection. When there are large temperature differences between the evaporator and condenser, the compressor must operate with high values of lift.

Figure 18. Example heat pump rating conditions for a central geothermal system



Heat pump selections should be coordinated with the ground heat exchanger design. Many projects will experience pressure to reduce the size of ground heat exchangers to reduce costs. This may lead to a larger seasonal temperature swing, which affects heat pump selection. Designers must consider the tradeoff between ground heat exchanger size and heat pump performance.

Heating Fluid Temperature

Most geothermal systems are designed with high efficiency in mind. The selection of heating loop supply temperature is one of the biggest levers available to designers for optimizing system efficiency.

A higher heating loop supply temperature means the heat pump compressor must work harder to transfer heat between the evaporator and condenser. Compressor energy consumption is proportional to the compressor “lift,” which is the temperature difference between the condenser leaving fluid and the evaporator leaving fluid.

Water cooled chillers are rated at Air-Conditioning, Heating, and Refrigeration Institute (AHRI) conditions of 44°F (7°C) leaving evaporator temperature and 94°F (34°C) leaving condenser temperature, which corresponds to a lift value of 50°F (10°C). Selecting a heat pump with a lift value of 100°F (38°C) results in roughly double the power draw and about half the efficiency.

Designers should also consider the effect that lower heat pump efficiency has on ground temperature. Increased compressor power draw means that less heating energy is pulled from the ground during heating season, potentially causing a seasonal upward drift in ground temperature.

Retrofit heat pump projects often encounter requirements for higher heating loop supply temperature. One option for retrofit projects is to conduct a heating loop stress test per the ASHRAE heat pump design guide, *Decarbonizing Building Thermal Systems: A guide for Applying Heat Pumps and Beyond*. This can help pinpoint specific coils that require higher heating temperatures. By retrofitting these coils, the entire system can benefit from lower installed cost and higher efficiency (lower operating cost). Geothermal systems can be expensive to install and allocating some money toward coil retrofits can significantly reduce heat pump cost and lower total project cost.

If the project must use higher-temperature heating, a booster heat pump may be added to the system. Some booster heat pumps can produce leaving condenser temperatures of 200°F (93°C) or higher. Designers may consider using a booster heat pump for specific loads that require higher temperatures, rather than using high temperatures for the entire heating loop.

See "[System Options and Alternatives](#)," p. 100, for an example of a booster heat pump in a geothermal system.

Antifreeze

Antifreeze may be required if any fluid temperature will drop below 40°F (4.44°C). The threshold temperature for using antifreeze depends on equipment requirements and engineer's preference.

Ground heat exchangers are not exposed to outdoor air temperatures. Therefore, antifreeze may not be needed in the ground heat exchanger, depending on the operating temperature and system design.

Outdoor air coils that are exposed to cold air temperatures require some form of freeze protection. Trane white paper CLCH-PRB052*, "Coil Freeze Prevention," addresses different methods of freeze protection for outdoor air coils. This white paper includes alternatives to antifreeze, such as freeze-stats, continuous pumping, air mixing baffles, and preheating.

The use of antifreeze negatively affects heat pump and system performance. If antifreeze is used, consider limiting concentration to the minimum required amount.

- Antifreeze has a lower specific heat than water, so a higher flow rate is required to transfer the same amount of heat.
- Antifreeze is more viscous than water, increasing system pressure drops and pump energy. The viscosity difference is greatest at low temperatures.
- Heat pump capacity is reduced when antifreeze is used due to differences in heat exchanger performance.
- Heat pump operating temperatures are more constrained with antifreeze due to lower heat exchanger effectiveness.

Burst Protection

As the temperature drops below the freezing point of the inhibited glycol solution, ice crystals begin to form. Because the water freezes first, the remaining glycol solution is further concentrated and remains fluid. The combination of ice crystals and fluid forms a flowable slush. The increase of system fluid volume resulting from slush formation is absorbed by the expansion tank. The solution never fully freezes, and therefore no damage is done to the unit or piping.

Burst protection is usually sufficient in systems that are inactive during winter and have adequate space to accommodate the expansion of an ice/slush mixture. Given a sufficient concentration of glycol for burst protection, no damage to the system will occur. Burst protection is also appropriate for closed-loop systems which must be protected despite power or pump failure (e.g., an air-cooled chiller that does not need to run during subfreezing weather).

Freeze Protection

Freeze protection is mandatory in cases where no ice crystals can be permitted to form or where there is inadequate expansion volume available, for example, a coil runaround loop. Also, HVAC systems that must start during cold weather following prolonged winter shutdowns may require freeze protection. However, freeze protection should be specified only when the fluid must remain 100 percent liquid at all times.

For either freeze or burst protection, the required concentration of glycol depends on the operating conditions of the system and the lowest expected ambient or fluid temperature. Often, the concentration is selected based on a temperature at least 5°F (-15°C) lower than the lowest anticipated design operating temperature. Table 9 is an excerpt from product information bulletins published by The Dow® Chemical Company. It is important that equipment selections are made at the required glycol concentration to ensure proper sizing.

Table 9. Typical antifreeze concentrations by volume

Temperature (°F)	Temperature (°C)	DOWTHERM™ SR-1 (ethylene glycol)		DOWFROST™ HD (propylene glycol)	
		Freeze	Burst	Freeze	Burst
20	-6.67	16.8%	11.5%	19.1%	12.8%
10	-12.22	26.2%	17.8%	30.9%	21.3%
0	-17.78	34.6%	23.1%	38.3%	25.5%
-10	-23.34	40.9%	27.3%	44.7%	29.8%
-20	-28.89	46.1%	31.4%	48.9%	31.9%
-30	-34.45	50.3%	31.4%	53.2%	35.1%
-40	-40	54.5%	31.4%	57.4%	37.2%
-50	-45.56	58.7%	31.4%	60.6%	37.2%
-60	-51.12	62.9%	31.4%	63.8%	37.2%

Systems that experience the mixing of fluids between loops require the same fluid type used in all loops unless an isolation heat exchanger is added.

Auxiliary Coolers

Systems that have an annual excess of heat (cooling dominant) may experience a year-over-year increase in ground temperature. One way to manage this upward drift in temperature is to reject some heat to air instead of to the ground. Dry coolers, evaporative cooling towers, adiabatic coolers, or air-cooled chillers may be used to reject excess heat in geothermal systems.

Auxiliary coolers are typically installed in the ground loop. Designers may choose between installing the auxiliary cooler upstream or downstream of the ground heat exchanger.

- Installing the auxiliary cooler **downstream** of the ground heat exchanger ensures that the ground heat exchanger receives the warmest temperature fluid and therefore has the opportunity to dissipate heat even if the ground temperature is warm [Figure 20](#).
- Installing the auxiliary cooler **upstream** of the ground heat exchanger maximizes the heat rejection potential of the auxiliary cooler. This arrangement may be preferred for systems that use a small auxiliary cooler for ground temperature management ([Figure 19](#)).
- If the ground temperature is saturated and unable to reject any additional heat, a ground loop bypass valve may be included. When the ground heat exchanger is bypassed, an auxiliary cooler functions the same in an upstream or downstream position.
- Dry coolers should be installed upstream of the ground heat exchanger to accommodate their higher operating temperature compared to cooling towers.
- Cooling towers must be closed circuit or use an isolation heat exchanger to avoid contamination in the ground loop.

Figure 19. Auxiliary cooler connected downstream of the ground heat exchanger

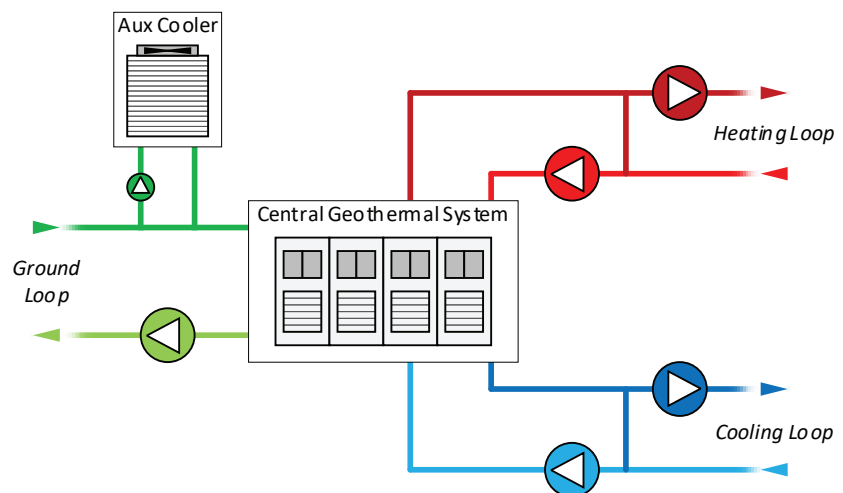
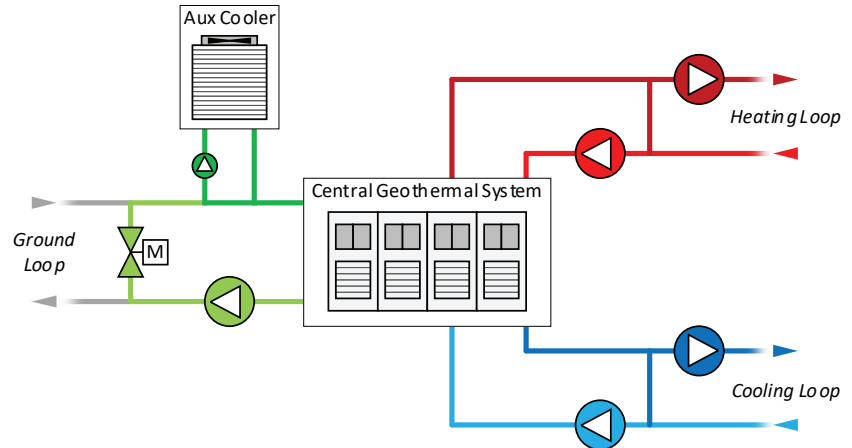


Figure 20. Auxiliary cooler connected downstream of the ground heat exchanger with ground loop bypass valve



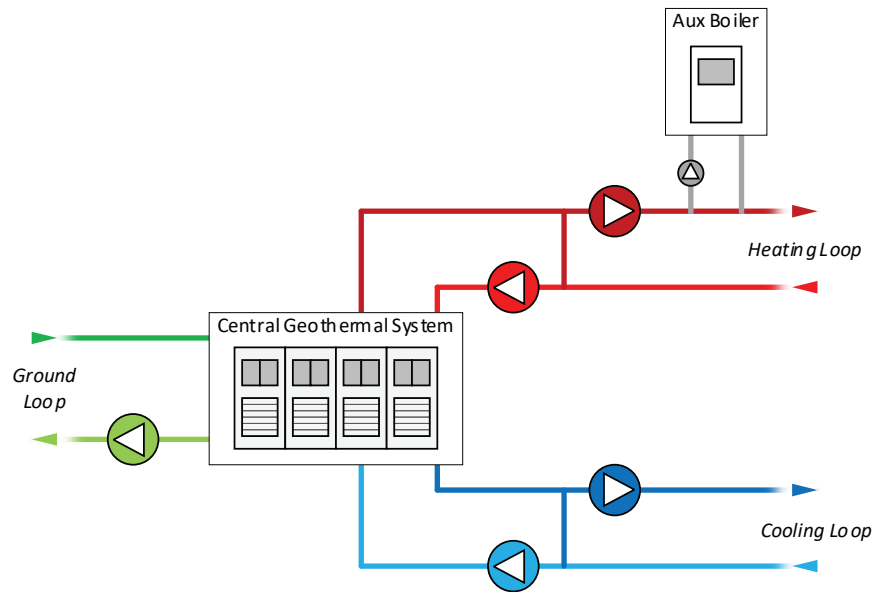
Example piping diagrams are provided for an auxiliary cooler in each of the five central geothermal systems. Refer to the "System Options and Alternatives" section for each central geothermal system type. For consistency, the example drawings represent an auxiliary cooler positioned downstream of the ground heat exchanger.

Auxiliary Boilers

Systems that have an annual deficiency of heat (heating dominant) may experience a year-over-year decrease in ground temperature. One way to manage this downward drift in temperature is by sourcing some heat from an auxiliary heating device.

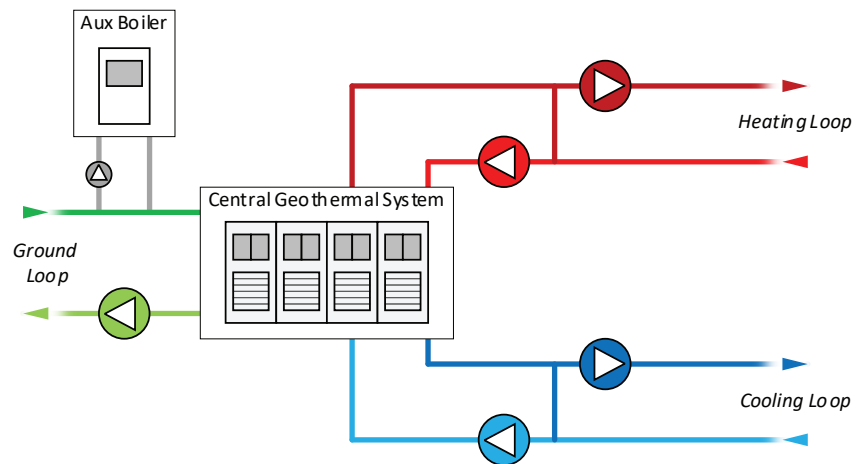
Auxiliary boilers are typically placed in the heating loop (Figure 21), enabling them to supplement the geothermal heat pump capacity, or to add redundancy to the system if a heat pump is down. Connecting auxiliary boilers downstream of the heat pumps allows the heat pumps to load up as much as possible, with the boilers used to trim the heating loop supply temperature.

Figure 21. Typical placement of auxiliary boiler in heating loop



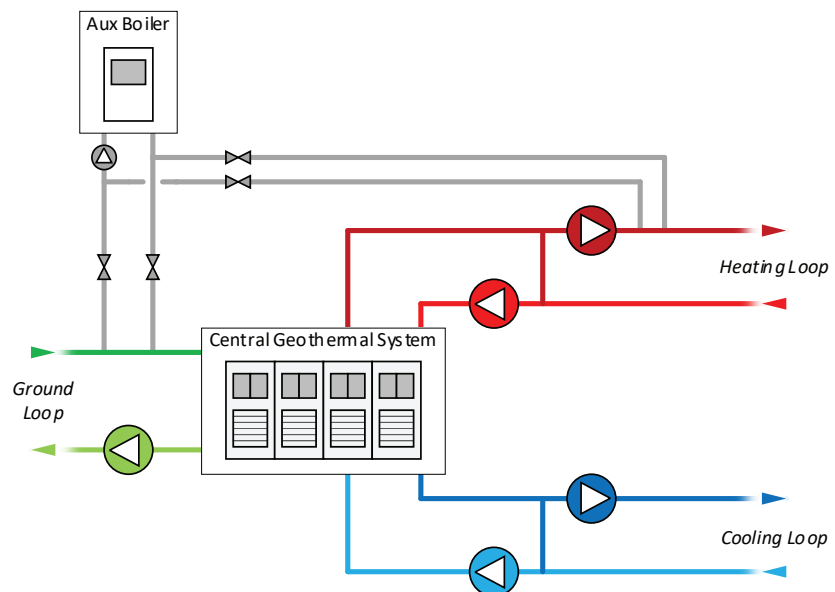
Auxiliary boilers may also be placed in the ground loop to keep the loop temperature warm enough to avoid using antifreeze (Figure 22). The tradeoff with this arrangement is that the system's heating efficiency is degraded because the heat pump must remain operating while the boiler is used.

Figure 22. Alternate placement of auxiliary boiler in the ground loop



Valves may be installed to switch connections of the auxiliary boiler between the ground loop and the heating loop.

Figure 23. Valve configuration allowing boiler connection to heating loop or ground loop



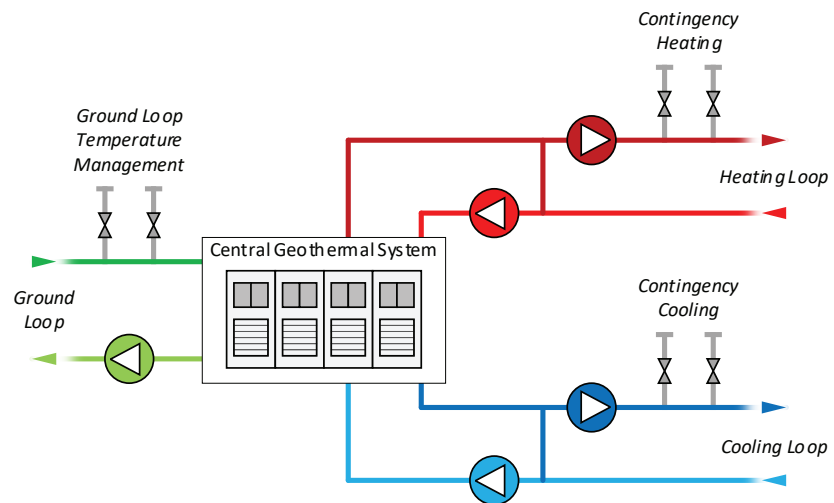
Example piping diagrams are provided for an auxiliary boiler installed in each of the five central geothermal systems (Figure 23). Refer to the “System Options and Alternatives” section for each central geothermal system type. For consistency, the example drawings represent an auxiliary boiler installed in the heating loop.

Contingency Cooling and Heating Connections

There is no reason to believe that a central geothermal system is any more or less reliable than a conventional chilled water/hot water HVAC system. For either system, a simple and low-cost contingency cooling method exists to mitigate the risk of long-term cooling loss. Designers may consider contingency connections in the heating loop, cooling loop, or ground loop (Figure 24).

- Heating loop contingency connections may be used to connect an auxiliary boiler or heat pump if the geothermal heat pump is down or has limited capacity.
- Cooling loop contingency connections may be used to connect to a temporary chiller if the geothermal heat pump is down or has limited capacity.
- Ground loop contingency connections may be used to connect to an auxiliary boiler or auxiliary cooler if the ground loop temperature is out of range. Refer to the section titled "[Ground Loop Temperature Management](#)," p. 34, for more information.

Figure 24. Contingency cooling and heating connections



Ground Loop Free Cooling

Ground loop free cooling is possible in geothermal systems when the ground loop temperature is cold, and there is a need for cooling. The concept is similar to the use of water-side economizers in chiller plants when outdoor air temperature is low.

Some geothermal systems may be capable of ground loop free cooling operation without additional valves or pipes. Most geothermal systems require design modifications to allow ground loop free cooling. Example methods to achieve ground loop free cooling are provided in the "System Options and Alternatives" section for each central geothermal system type.

“Partial free cooling” is generally not advisable for geothermal systems. Partial free cooling is commonly used with water side economizers. The economizer heat exchanger provides part of the cooling capacity, and chillers are used for additional capacity. The problem with this approach in geothermal systems is that free cooling requires the ground loop to be connected to the cooling loop. If the geothermal heat pump provides additional cooling, its condenser must also be connected to the ground loop. Simultaneous connection of the ground loop, cooling loop, and heat pump condenser may be hard to control and is likely to cause poor system efficiency.

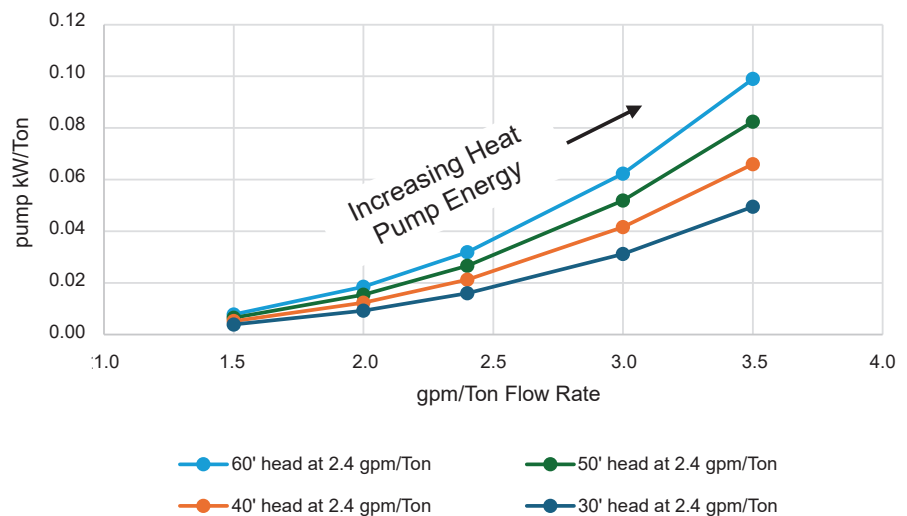
Ground Loop Pump Energy

In Chapter 44, page 7 of the 2024 ASHRAE Handbook for Systems and Applications, a formula is provided for pump power based on flow rate and differential pressure. This formula ignores inefficiencies in the pump, motor, and Variable Frequency Drive (VFD). This formula applies to water and correction factors must be applied for systems that use glycol.

$$Ideal\ Pump\ Power = \frac{flow(GPM) * differential\ pressure(ft\ head)}{3960}$$

As flow rate changes in the ground heat exchanger, the differential pressure value changes with flow **squared**. This means that pump power changes with flow rate **cubed**. Figure 25 illustrates pump energy as a result of flow rate and ground loop differential pressure. Flow rate and pump power are normalized per ton, so it can be combined with heat pump efficiency in the next step.

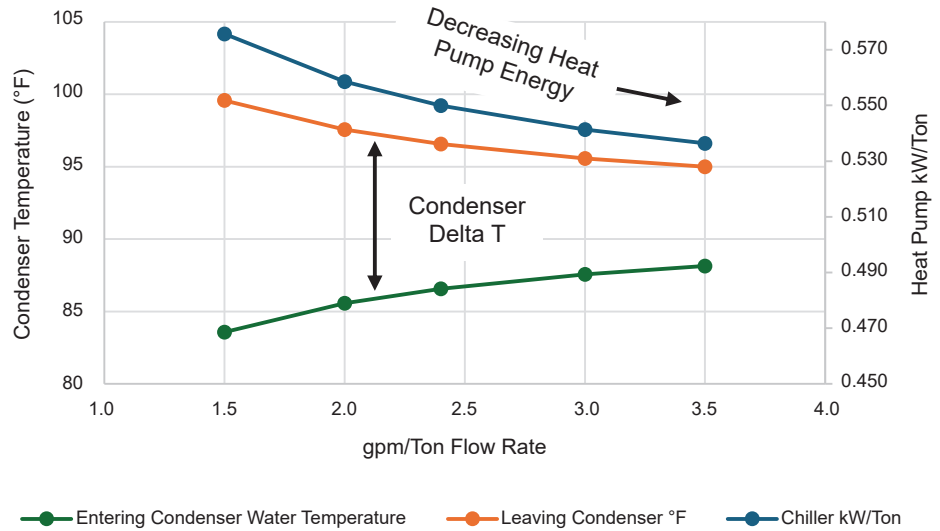
Figure 25. Pump energy vs. flow rate and differential pressure



Geothermal System Design Considerations

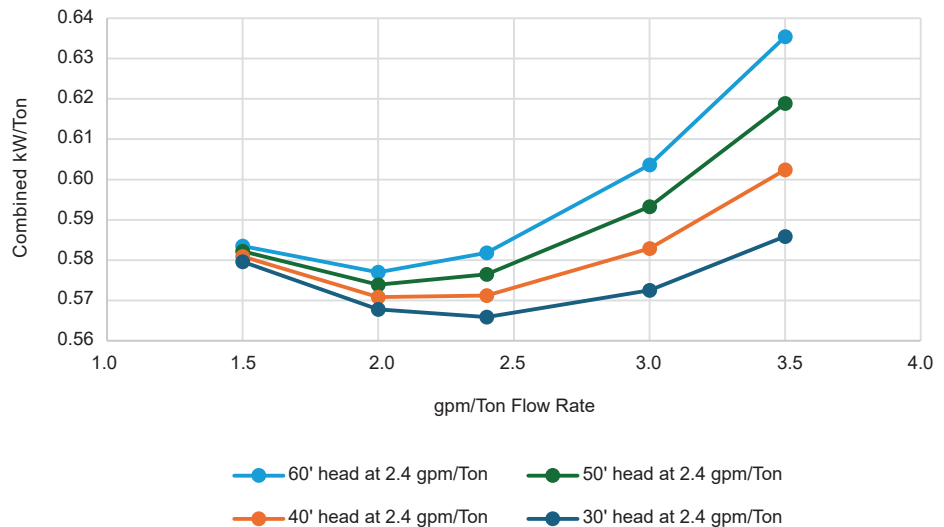
Higher ground loop flow rate means a lower delta T on the heat pump condenser. A lower delta T means a lower condenser leaving temperature. This results in reduced compressor lift and better compressor efficiency. Figure 26 illustrates the correlation between flow rate, leaving condenser temperature, and heat pump cooling efficiency.

Figure 26. Heat pump efficiency vs. flow rate (lower delta T)



The combined system efficiency must consider pumping energy **and** heat pump energy together. Figure 27 shows an optimal system efficiency between 2.0gpm/Ton to 2.4gpm/Ton (1.26 L/s per kW to 2.498 L/s per kW), depending on the ground loop head pressure.

Figure 27. Combined heat pump and ground loop pump power vs. flow rate



The results presented here represent a specific model of heat pump and ground loop head of 30 ft to 60 ft (9.14 m to 18.29 m). Designers should use project specific heat pump efficiency and ground loop pressure drop when calculating the optimal condition. Ground loop delta T values of 10°F to 12°F (-12 °C to -11 °C) may be a good starting point. Ground loop flow rate may be modulated at part load to maintain the delta T value.

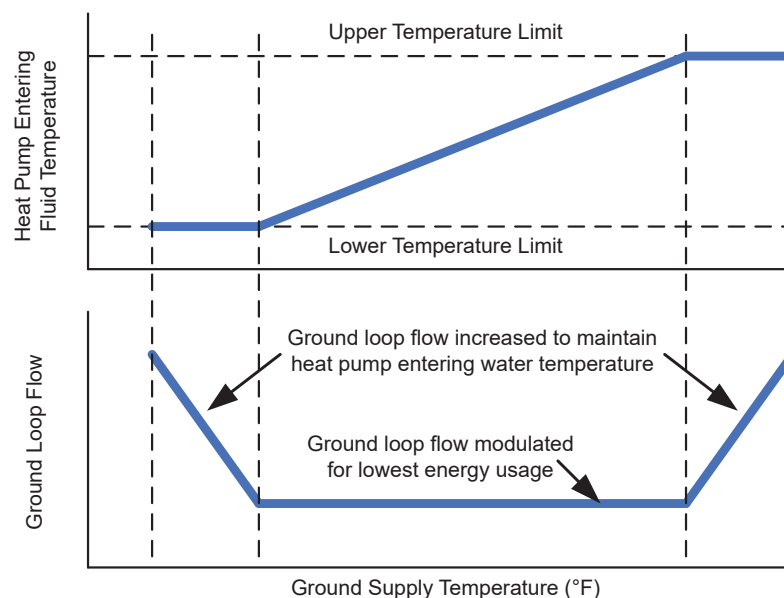
- Systems with low pressure drop ground heat exchangers benefit from more flow. Improvements to heat pump efficiency outweigh the increased pumping energy (up to a point).
- Systems with high pressure drop ground heat exchangers benefit from less flow. The increase in pump energy outweighs the improvement of heat pump efficiency.

Note: *Ground loop pump optimization is similar to cooling tower optimization. In both scenarios, there is a tradeoff between pump/fan energy and heat pump/chiller efficiency. Optimal **system** efficiency can be found by overlaying the energy usage of all equipment and finding the conditions that result in the lowest total energy usage.*

As the ground return temperature approaches the heat pump entering fluid temperature limits, it may be necessary to increase the ground loop flow rate above the optimal value to keep the heat pump entering fluid temperature within the limit values (Figure 28). The following pumping strategy may be used:

- When the heat pump entering fluid temperature is above the minimum value and below the maximum value, the ground loop flow rate is modulated to achieve the optimal delta T value.
- As the heat pump entering fluid temperature (ground return temperature) approaches the minimum or maximum limit value, ground loop flow is modulated to maintain the ground return temperature within the limit values. This overrides the delta T based optimal flow control.

Figure 28. Ground loop flow control strategy that optimizes system efficiency and maintains heat pump entering fluid temperature



Ground Loop Temperature Management

Geothermal systems that extract more heat from the ground in heating mode than is rejected to the ground in cooling mode may experience a year-over-year decrease in ground loop temperature. The following options may be used to mitigate “depleted” (low) ground temperature.

- Add an additional source of heat such as an auxiliary boiler or Air-to-Water Heat Pump (AWHP).
- Disable airside economizing when permitted by energy codes.

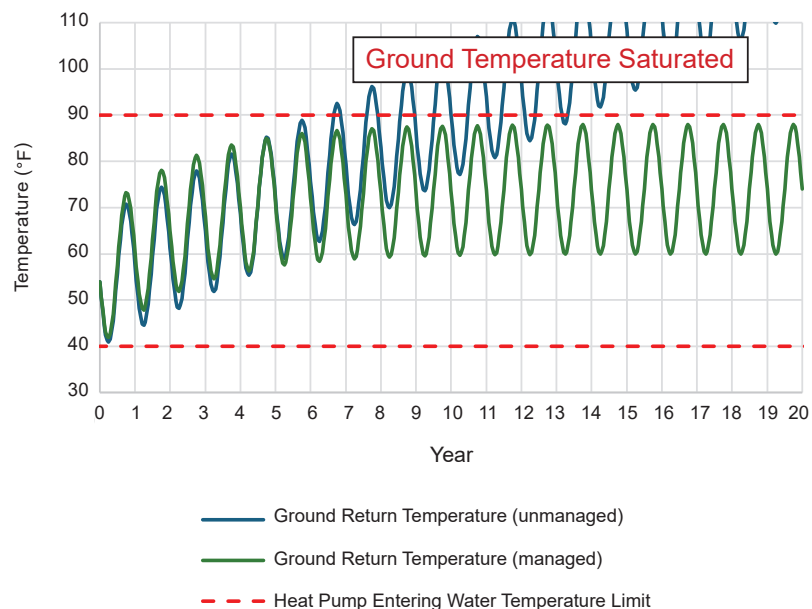
Geothermal systems that reject more heat to the ground in cooling mode than is extracted in heating mode may experience a year-over-year increase in ground loop temperature. The following options may be used to mitigate “saturated” (high) ground temperature.

- Add an auxiliary cooler.
- Enable airside economizing.
- Optimize pumping energy.

System controls may include automated ground temperature management to adjust for fluctuating temperature conditions. These adjustments are made on a very slow time scale—such as weekly, monthly, or seasonally—and do not require a fast response. This prevents the system from overreacting to short-term temperature swings.

Figure 29 shows a hypothetical ground loop that saturates at high temperature after seven years of operation. Ground loop temperature management is used to keep heat pump entering fluid temperature within the acceptable range of values.

Figure 29. Ground loop temperature management prevents saturated ground temperature



Loop Volume and Buffer Tanks

Loop volume provides thermal inertia to the system, allowing time for the heat pump controls and system controls to react to changes in system operation. More loop volume means that transients in the system are slower, giving the controls more time to react.

Loop time is defined as the time it takes for a molecule of fluid to travel from the heat pump, through the system, and back to the heat pump. More loop volume results in longer loop times.

Loop volume requirements are manufacturer specific and vary by product and application. Failure to meet the loop time requirements may lead to unstable system control or excessive compressor cycling.

Heat pumps that use compressor staging to maintain leaving fluid temperature often require longer loop time (larger loop volume). Heat pumps that include unloading devices—such as slide valves or VFDs—can often respond more quickly to changes in system operation without cycling compressors.

Geothermal systems may include three fluid loops: a ground loop, a heating loop, and a cooling loop. The loop volume requirement applies to all three loops.

If the minimum loop volume is not met, buffer tanks may be added to the system. Buffer tanks should be installed on the loop return lines, upstream of the heat pumps. This slows down temperature transients, giving the heat pump more time to react.

ASHRAE 90.1-2022 Changeover System Requirements

Refrigerant changeover and hydronic changeover central geothermal systems must comply with ASHRAE 90.1-2022 changeover system requirements. These requirements are:

6.5.2.2.2 Two-Pipe Changeover System. Systems that use a common distribution system to supply both heated and chilled water are acceptable, provided all the following are met:

- a. The system is designed to allow a dead band between changeover from one mode to the other of at least 15°F (-9.45°C) outdoor air temperature.*
- b. The system is designed to operate and is provided with controls that allow operation in one mode for at least four hours before changing over to the other mode.*
- c. Reset controls are provided that allow heating and cooling supply temperatures at the changeover point to be no more than 30°F (-1.11°C) apart.*

Geothermal System Design Considerations

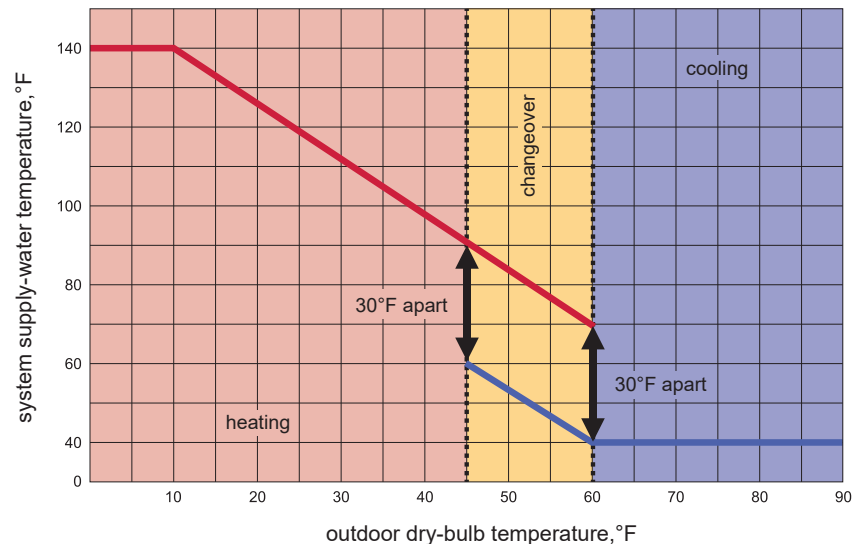
Designers may use different strategies to satisfy the ASHRAE 90.1-2022 changeover requirements. Examples include:

Manual operation. Operators may disable the system when outdoor temperature is moderate (e.g., 40°F (4°C)), allowing system temperature to stabilize before re-enabling the system in the opposite mode.

ASHRAE Guideline 36 water plant reset. Setpoint temperature and pump pressure are reset based on critical valve position.

Automated temperature reset based on outdoor ambient temperature. The [Figure 30](#) depicts an example of a system complying with the changeover requirements.

Figure 30. Example of a system supply-water temperature complying with the changeover requirements



The system uses outdoor air temperature to determine whether it operates in heating or cooling mode and to reset the water leaving temperature setpoints accordingly ([Figure 30](#)).

Heating Mode

- When the outdoor temperature is colder than 45°F (7°C), the system operates in heating mode.
- The setpoint for water leaving the heat pump is reset based on the current outdoor dry-bulb temperature.
- At 10°F (-12°C) and below, the hot water setpoint is 140°F (60°C).
- Between 10°F (-12°C) and 60°F (16°C), the hot water setpoint is reset proportionally between 140°F (60°C) and 70°F (20°C).

Cooling Mode

- When the outdoor temperature is 60°F (16°C) or warmer, the system changes over to cooling mode, and the setpoint temperature for the water leaving the heat pump is 40°F (4°C).
- When the outdoor temperature is between 60°F (16°C) and 45°F (7°C), the chilled water setpoint is reset proportionally between 40°F (4°C) and 60°F (16°C).
- When the outdoor temperature drops to 45°F (7°C), the system changes over to heating mode and the setpoint for water leaving the heat pump is 90°F (32°C).

Changeover Timing

- When in heating mode, if the outdoor temperature rises above 45°F (7°C), the system remains in heating mode due to the 15°F (-9°C) changeover deadband.
- When in cooling mode, if the outdoor temperature drops below 60°F (16°C), the system remains in cooling mode due to the 15°F (-9°C) changeover deadband.
- The system-level controller includes a timer to prevent this changeover from occurring within four hours of the last time the system changed modes.



Airside Considerations

Heating Design

The central geothermal system is a chiller/heater-based application. This system characteristic means the design hot water temperature needs to be carefully considered since the vapor compression cycle is more efficient at producing lower grade heat. To maximize the efficiency of the chiller/heater, it is desirable to control the leaving condenser water temperature to as low as possible (typically, 105°F to 140°F (41°C to 60°C)) so that compressor work is minimized. Of course, this reduction is traded against condenser and heating system pump energy use. One way to keep the condenser water temperature low is by carefully considering the design leaving air temperature of the heating system. ASHRAE Standard 90.1-2022 limits the temperature at which warm air is delivered to a zone with overhead heating to no greater than 20°F (-7°C) above the zone temperature setpoint. Assuming a 70°F (21°C) heating setpoint, a 90°F (32°C) heating supply air temperature is quite achievable from lower-temperature water.

There are numerous options for making use of low-temperature hot-water supply (HWS) in both centralized and zone-level heating equipment. Many can be applied in existing buildings when considering electrification.

- High-capacity heating coils: For central air-handling units, heating coil options are available that can provide the required heating capacity when using a lower HWS temperature, at an acceptable waterside delta T (flow) and airside pressure drop.
- Changeover coils: For both terminal equipment and central air-handling units, consider using changeover coil control. That is, using the same coil for both cooling and heating. Cooling coils are typically much larger (more rows) than heating coils. Using the cooling coil for heating also enables the use of a lower HWS temperature, increased waterside delta T, and low waterside and airside pressure drops. Six-way control valves and high-accuracy pressure independent control (PIC) valves are widely available to enable changeover operation.
- Radiant heaters: Radiant heating systems are commonly designed for a lower HWS temperature, making them a natural complement to AWHP-based systems.
- Hydronic Branch Conductor: This is a valve control unit used in a distributed hydronic heating and cooling system that directs either hot water or chilled water to-and-from an area of the building, based on that area's current need for heating or cooling. It simplifies zone comfort by using the same branch piping for both cooling and heating, uses dual-purpose (changeover) coils in the terminal units, adapts to varying heating and cooling zone demands, and improves energy efficiency by allowing for the use of a lower HWS temperature. See the "Hydronic Branch Conductor" application guide for more information (APP-APG024*).

What HWS temperature is needed to heat a space? It varies depending on the application. [Table 10](#) summarizes common minimum HWS supply temperatures, and the corresponding delta T ranges, that can satisfy typical commercial heating applications.

Table 10. Hydronic heating conditions for various airside systems

Equipment	Minimum Heating Water Supply Temperature	Expected System delta T at Minimum Heating Water Supply Temperature
DOAS air-handling unit	>80°F (>27°C)	20°F to 40°F (-7°C to 4°C)
central air-handling unit/VAV	80°F to 105°F (27°C to 41°C)	18°F to 30°F (-8°C to -1°C)
single zone VAV air-handling	100°F to 105°F (38°C to 41°C)	12°F to 26°F (-11°C to -3°C)
VAV terminal units (4-row coil)	100°F to 105°F (38°C to 41°C)	8°F to 20°F (-13°C to -7°C)
fan coil units with changeover coil	80°F to 115°F (27°C to 46°C)	8°F to 12°F (-13°C to -11°C)

A dedicated outdoor-air system (DOAS) often includes an energy recovery device for preconditioning the entering outdoor air, and its supply-air temperature during the heating season is typically around 70°F (21°C). This allows a DOAS unit to be easily selected with a low HWS temperature and a relatively-high delta T.

The most challenging application is in-space fan-coil units. This application typically requires the use of a changeover coil. In most cases, the cooling coil in a fan-coil unit, which supplied 55°F (13°C) air using 45°F (7°C) chilled water, can changeover to heat the same flow rate of air from 60°F (16°C) to 95°F (35°C) using 105°F (41°C) HWS temperature. Even though the DOAS unit (which is commonly part of a fan-coil system) could use an even lower HWS temperature, this may require significant upsizing of the fan-coils. In general, a HWS temperature of 100°F to 115°F (38°C to 46°C) is needed to avoid the need to upsize the fan-coils in an existing building.

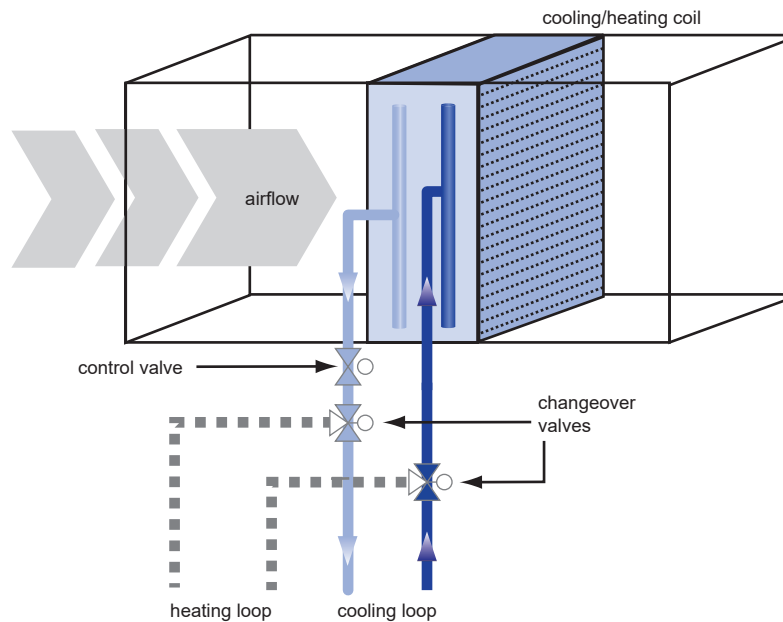
Careful attention to coil selection can allow systems to successfully operate with 100°F to 110°F (38°C to 43°C) HWS temperature for any climate. For more information, see the Trane *Engineers Newsletter* titled “Heating with Lower-Temperature Hot Water” (ADM-APN084-EN).

Multiple-Zone Variable Air Volume (VAV) Systems

The hot water coil(s) in a VAV air handler was historically limited to one or two rows because the entering water temperature was typically high (for example, 180°F (82 °C)) which gives the coil tremendous heating capacity. The lower entering water temperature of a central geothermal system may necessitate the need for a deeper heating coil, thus increasing equipment first cost and airside pressure drop.

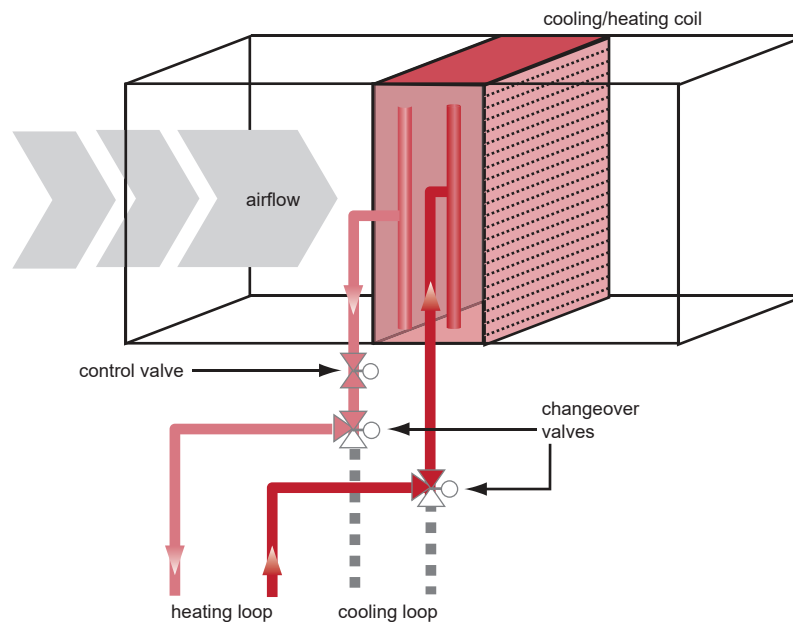
However, since the water in the heating, cooling, and ground-source loops of a central geothermal system are interconnected to facilitate simultaneous heating and cooling operation, an opportunity exists to use a changeover strategy at the air handler, thus eliminating the need for a dedicated central system heating coil (Figure 31).

Figure 31. Single-coil VAV air handler: Cooling mode



When a demand for heat exists at the air handler, a changeover valve is activated and water from the heating system is provided to the cooling coil. Operation of the coil control valve is then reversed. This high capacity coil helps keep the delta T high on the heating system and therefore saves pump and fan energy, because a heating coil is not required. The elimination of the dedicated heating coil reduces equipment first cost (Figure 32).

Figure 32. Single-coil VAV air handler: Heating mode



As documented in the Engineers Newsletter Volume 51-4 (2022), *Heating with Lower-Temperature Hot Water*, VAV terminal units must be capable of heating the zones with a lower hot water temperature as well. This function may require multiple-row heating coils. At this point, careful consideration for the heating discharge air temperature is required. A 90°F to 95°F (32°C to 35°C) heating discharge air temperature is possible with a 130°F (54°C) entering water temperature, assuming typical minimum primary airflow settings. The careful implementation of a supply air temperature reset strategy can allow the system primary air temperature to be warmer than the cooling design setpoint when reheat or space heating is required. This provides valuable capacity relief for the VAV heating coil, especially for non-fan-powered systems. When using parallel-fan-powered equipment, the heating coil may need to be located on the discharge side of the terminal unit (in lieu of the plenum inlet side) to allow all the discharge air to flow through the coil and reduce the required coil leaving air temperature (Figure 32).

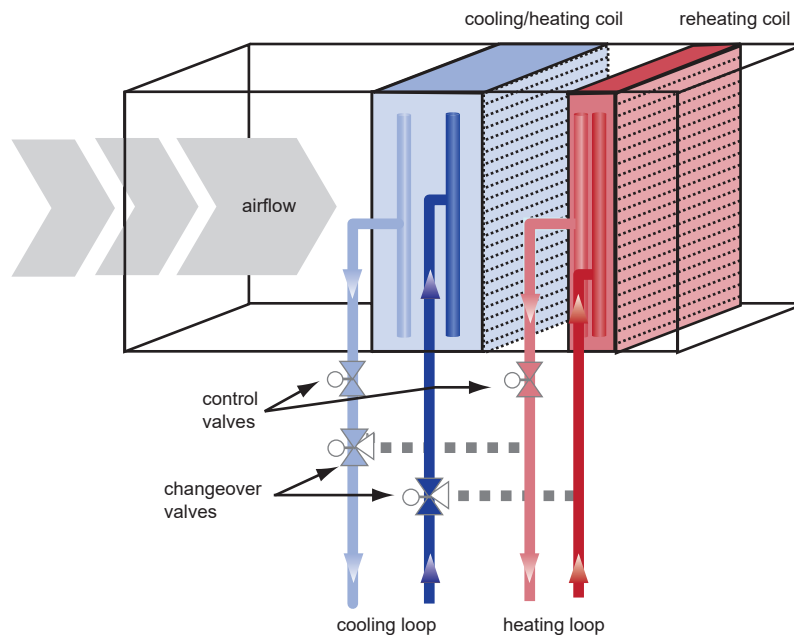
Fan Coil Systems with Separate 100 Percent Outdoor Air Units

Like the VAV terminal units, careful attention to the required fan-coil heating discharge air temperature is important. A multiple-row heating coil may be required, assuming a heating discharge air temperature of 90°F (32°C) or higher is needed.

A 100 percent outdoor air unit often requires three coils (Figure 33). The first is a preheat coil for heating, followed by a cooling coil for cooling and dehumidification, and sometimes a reheat coil for dehumidification control. Heating with lower-temperature water demands greater coil heat transfer surface for the same capacity. This issue is most noticeable in 100 percent outdoor air systems where heating capacity requirements are large.

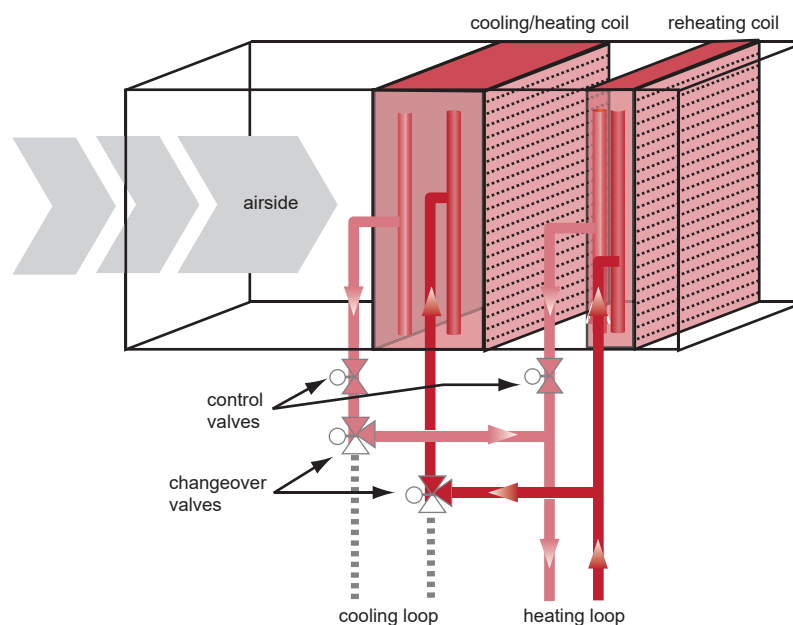
It is possible that a one- or two-row heating coil would not be adequate for heating outdoor air with a lower-temperature water. An alternate strategy to consider utilizes only two coils. The deep cooling coil of a 100 percent outdoor air unit doubles as a heating coil in an “ultra” heat mode. This strategy is an effective way of eliminating the need for a preheat coil in air-handling units that perform seasonal heating and reheating.

Figure 33. Two-coil dedicated outdoor air handler: Cooling mode



The “ultra” heat mode (Figure 34) is entered when a call for heating exists (as opposed to reheating) at the air-handling unit and exits the mode when a call for mechanical cooling returns. Since all of the water in the central geothermal system is interconnected, the heating water is simply diverted through the cooling coil and can be simultaneously passed to the reheat coil for additional heat capacity if required. The cooling coil is the first stage of heating and the reheat coil is the second stage. This additional coil surface should allow the unit to successfully heat the outdoor air to the required temperature with lower-temperature hot water.

Figure 34. Two-coil dedicated outdoor air handler: “Ultra” heat mode



Unit Ventilator Systems

The heating coil of a unit ventilator is located in tight quarters, immediately adjacent to an exterior wall. Protecting the coils from freezing conditions can be critical for some climates, and the use of glycol for this purpose may be unavoidable. However, the presence of glycol causes a dramatic drop in the coil capacity.

The limited number of rows of heating coil available in a four-pipe system, combined with a modest hot water temperature of 130°F (54°C), may not be adequate to fulfill the necessary heating requirements. A two-pipe system may provide the solution. A two-pipe system may work from a comfort standpoint by the ability to air economize during the “shoulder” season, which allows the central plant to transition to heating when necessary without forfeiting cooling capability. This allows a high-capacity, four-row coil to be used for heating so that the heating capacity needs of the space could be met.

Coordinated, Load-Shedding Economizer Control

Central air handlers often have outdoor air economizers to reduce cooling energy use. With standard forms of economizer control, cool outdoor air is used whenever possible, allowing mechanical cooling to be reduced or shut off. In a system equipped with heat recovery, there will be times when the heat rejected by the mechanical cooling equipment could instead be used to satisfy a heating load. Rather than allow full, or any, economizer cooling, it would save energy to disable (or reduce) the economizer cooling and use the chiller/heater for cooling and use its rejected heat for useful heating. This type of modified economizer operation is called **load-shedding economizer** control. Its goal is to balance the energy being recovered from the building cooling loads and the energy required by the heating loads. In some geothermal systems, this may reduce the ground-source flow and pumping energy and may provide warmer evaporator water to the heating unit, raising its operating efficiency. The cheapest Btu is the one already in the building.

This control logic can also be extended to the balancing of the annual energy rejected to the ground source. Assuming a specific building was seasonally cooling load dominant, the air handler economizers could be controlled to use outdoor air for cooling rather than operating the heat pump in cooling mode, which would reject heat to the ground source. The result could be less ground-source heating and possibly allow the installation of a smaller field.

To maximize the benefit of such logic, the facility manager or facility service provider should perform ongoing as well as an annualized evaluation of the building heating and cooling loads to determine the optimum load-shedding economizer control setpoints.

Freeze Protection

Freeze protection for the system may be needed for two reasons:

- The potential for freezing resulting from low leaving evaporator temperatures during heating operation.
- The potential for freezing due to cold outdoor air coming in contact with an air-handling unit coil or with exposed outdoor piping.

It is important to understand the specific freeze risk issue being addressed when selecting an appropriate freeze avoidance strategy.

Avoiding the use of glycol antifreeze solutions is desirable because both ethylene and propylene glycol negatively impact system efficiency and equipment performance, they are expensive in the quantity required for the system, and they expose groundwater to contamination if leaked.

Low Evaporator Temperature Protection

The greatest risk of excessively low evaporator temperature occurs when in the heating mode. Heat is extracted from the ground source through the evaporator water loop. As the ground-source temperature drops during the heating season, the chiller/heater can potentially lower the evaporator leaving water temperature enough to risk heat exchanger freezing. This occurrence is prevented by limiting the leaving water temperature. A helical rotary scroll chiller might provide this protection as a standard feature. For a chiller without this built-in protection, the plant control will be required to provide capacity limiting for chiller protection. If the building's heating demand is not satisfied as a result of the chiller protecting load limiting, supplemental heat from a boiler is utilized to meet the remaining load.



Refrigerant Changeover Central Geothermal System

The refrigerant changeover central geothermal system can operate in either heating mode or cooling mode (but not at the same time). This system takes advantage of reversible heat pumps, simplifying the hydronic design, and reducing the number of external valves required.

System Requirements and Design Considerations

The base configuration of a refrigerant changeover central geothermal system (Table 11, p. 47) has the following attributes:

- Changeover between heat mode and cooling mode is achieved using refrigerant valves integral to the modular heat pump chillers.
- Variable primary flow pumping is used to reduce the number of pumps in the ground loop and distribution loop. Decoupled primary-secondary pumping could also be used.
 - Modular heat pumps are assumed to include internal flow control valves (closed to isolate flow in modules that are not running). This creates a stepped, variable flow in the system.
- An optional head pressure control valve (V-1 in Figure 35, p. 47) is shown for systems that operate in cooling mode with low ground return temperature. Head pressure control may also be needed in heating mode with high ground temperature. V-1 may be omitted if the heat pump chiller includes an integral head pressure control function.
- Pump speed is controlled based on feedback from differential pressure sensors. Optional flow meters may be added for diagnostic function.
 - The base system uses pump speed to control heat pump differential pressure and a bypass valve to control system differential pressure. Refer to the section "System Options and Alternatives," p. 50, for more details.
- The base design assumes that fluid in the ground loop is isolated from fluid in the distribution loop. Designers should confirm this assumption with the heat pump manufacturer.

In addition to the base configuration, section "System Options and Alternatives," p. 50, addresses the following system alternates:

- Pump and flow control strategies
- Auxiliary cooler
- Auxiliary boiler
- Scaling to higher capacity

The refrigerant changeover central geothermal system must comply with ASHRAE 90.1-2022 changeover requirements. Refer to the section "Geothermal System Design Considerations," p. 10, earlier in this manual for additional details.

Component Descriptions

Figure 35. Refrigerant changeover central geothermal system

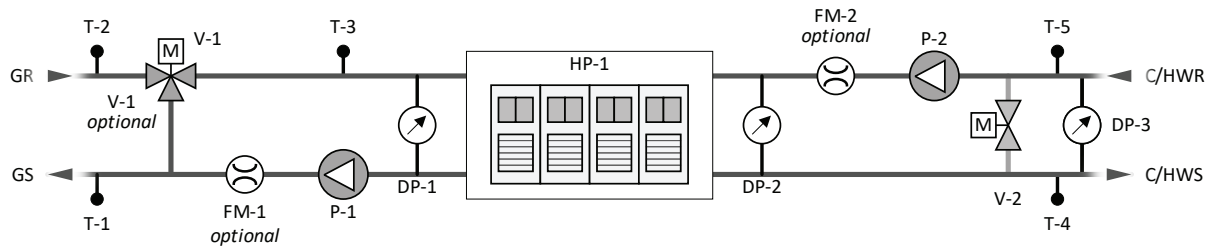


Table 11. Component list for refrigerant changeover central geothermal system

Component	Description
HP-1	Geothermal heat pump: The Geothermal heat pump is a reversible refrigeration cycle water-to-water heat pump. It can function in heating mode (moving heat from the ground loop to the distribution loop) or in cooling mode (moving heat from the distribution loop to the ground loop).
P-1	Ground loop pump: The ground loop pump provides flow through the ground loop and the geothermal heat pump. It controls differential pressure at the heat pump (DP-1). Optional flow meter FM-1 may be used for monitoring and diagnostics.
P-2	Distribution loop pump: The distribution loop pump provides flow to the distribution loop and the heat pump. It controls differential pressure at the heat pump (DP-2). Optional flow meter FM-2 may be used for monitoring and diagnostics.
V-1 (optional)	Ground loop bypass: The ground loop bypass valve is a modulating control valve that provides head pressure control when cooling with low ground return (GR) temperature. Consult the heat pump manufacturer to determine if this is needed.
V-2	Minimum flow bypass: <ul style="list-style-type: none"> The minimum flow bypass is a modulating control valve required in variable primary flow systems to maintain the heat pump's minimum flow rate when distribution flow rate is low. The minimum flow bypass is controlled based on the distribution loop differential pressure (DP-3). The bypass valve should be installed near the end of the distribution loop to prevent short loop transit times when the bypass opens. A hard-wired connection should be used for bypass valve controls to ensure quick response time.
T1, T2, T3	Ground loop temperature sensors: Ground loop temperature sensors T-1 and T-2 measure the fluid temperature entering and returning from the ground heat exchanger. These temperatures may be used for ground loop flow optimization. Optional temperature sensor T-3 is added when head pressure control valve V-1 is used in the system.
T4, T5	Distribution loop temperature sensors: Distribution loop temperature sensors T-4 and T-5 monitor the heating/cooling loop fluid temperatures.
DP-1	Heat pump ground loop differential pressure sensor: Differential pressure sensor DP-1 monitors fluid differential pressure across the ground loop side of the heat pump.
DP-2	Heat pump pressure sensor: Differential pressure sensor DP-2 monitors fluid differential pressure across the distribution loop side of the heat pump.
DP-3	Distribution loop differential pressure sensor: Differential pressure sensor DP-3 monitors fluid differential pressure at a remote point in the distribution system.
FM-1, FM-2 (optional)	Ground loop and distribution loop flow meters: A flow meter may be added to the ground loop and/or distribution loop to verify that pump differential pressure control results in the correct flow rate. A mismatch between differential pressure and flow measurements may indicate flow obstructions such as heat exchanger fouling or clogged strainers. Diagnostic warnings may be used to alert operators of potential flow issues.

System Operation and Control

The refrigerant changeover central geothermal system responds to a BAS call for heating or cooling. The BAS issues an operating mode command (heating or cooling) and a temperature setpoint command to the heat pump equipment controller. Changeover between heating and cooling modes must comply with ASHRAE 90.1-2022, section 6.5.2.2.2 (see section "[ASHRAE 90.1-2022 Changeover System Requirements](#)," p. 35, for requirements). The refrigeration changeover central geothermal system does not provide a heat recovery function.

Cooling Mode

In cooling mode, the geothermal heat pump positions its internal reversing valves so that the ground loop heat exchanger functions as the condenser, and the distribution loop heat exchanger functions as the evaporator (Figure 36). The geothermal heat pump modulates capacity to satisfy cooling setpoint temperature by staging compressors and modules. The ground loop pump, distribution loop pump, and minimum flow bypass valve are used to control fluid flow and differential pressure in the system. See Table 12 for more details.

Figure 36. Refrigerant changeover geothermal system in cooling mode

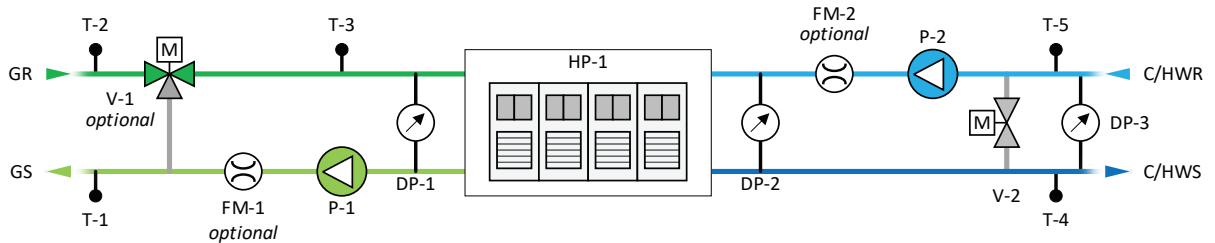


Table 12. Control logic for refrigerant changeover geothermal system in cooling mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain the leaving evaporator temperature at a cooling loop supply setpoint	Sensors in HP-1
P-1	Modulates to maintain heat pump condenser differential pressure	DP-1
P-2	Modulates to maintain heat pump evaporator differential pressure	DP-2
V-1 (optional)	<ul style="list-style-type: none"> Modulates to maintain minimum head pressure for HP-1 Check with the heat pump manufacturer for minimum head pressure requirements 	Sensor in HP-1, or T-1 and T-4
V-2	Modulates to maintain distribution supply pressure	DP-3

Heating Mode

In heating mode, the geothermal heat pump positions its internal reversing valves so that the ground loop heat exchanger functions as the evaporator, and the distribution loop heat exchanger functions as the condenser (Figure 37). The geothermal heat pump modulates capacity to satisfy the heating setpoint temperature by staging compressors and modules. The ground loop pump, distribution loop pump, and minimum flow bypass valve are used to control fluid flow and differential pressure in the system. See Table 13 for more details.

Figure 37. Refrigerant changeover geothermal system in heating mode

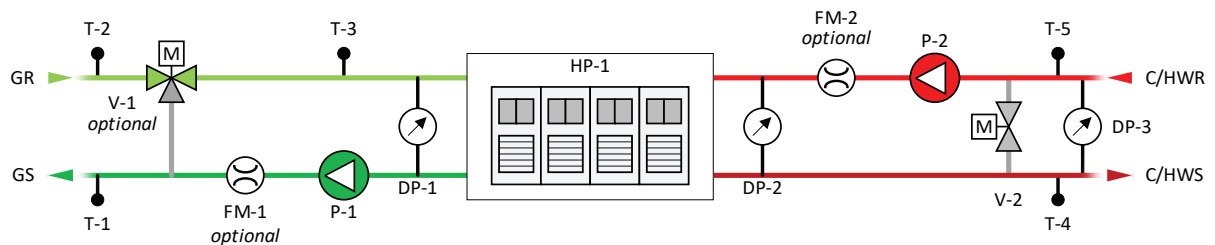


Table 13. Control logic for refrigerant changeover geothermal system in heating mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain leaving condenser temperature at a heating loop supply setpoint	Sensors in HP-1
P-1	Modulates to maintain heat pump evaporator differential pressure	DP-1
P-2	Modulates to maintain heat pump condenser differential pressure	DP-2
V-1 (optional)	Closed <i>Note: V-1 does not require a mode-dependent, forced closure. It will naturally close because head pressure control is not needed.</i>	N/A
V-2	Modulates to maintain distribution pressure	DP-3

System Options and Alternatives

Pump and Flow Control

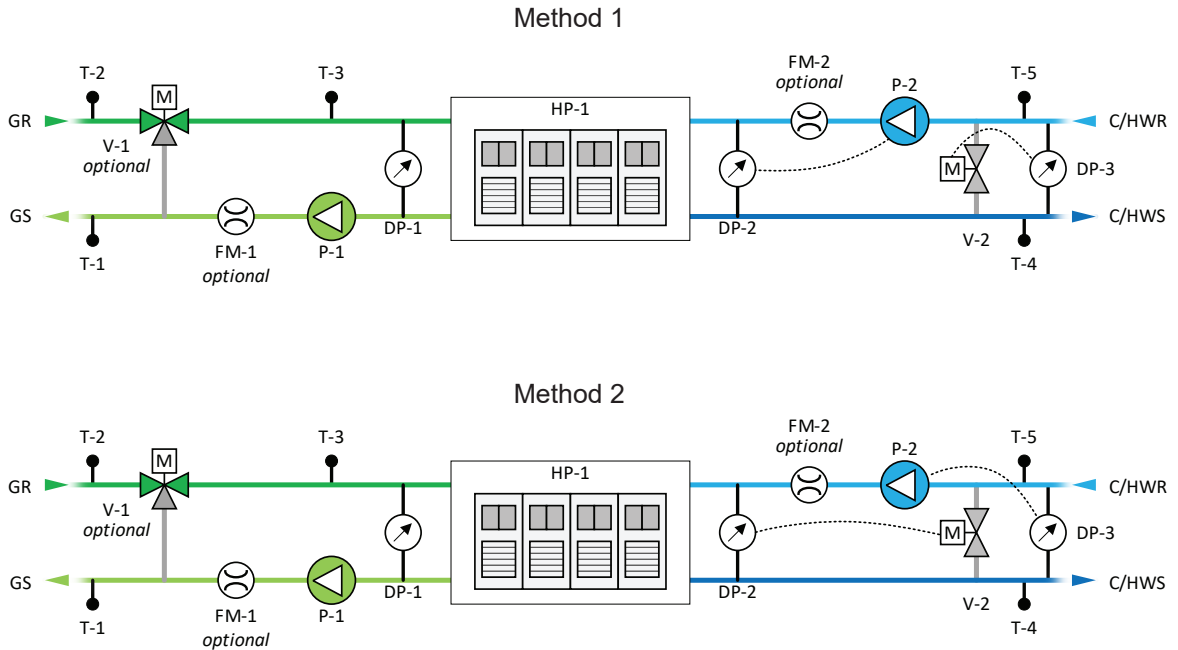
The Trane Application Guide PKG-APG001*-EN “Modular Heat Pump Chillers in Variable Primary Flow Hydronic Systems,” describes two methods for controlling Variable Primary Flow (VPF) pumps and bypass valves (Table 14).

Table 14. Methods of controlling VPF pumps and bypass valves

	Method 1	Method 2
Primary Pumps	Modulates to maintain heat pump differential pressure	Modulates to maintain system differential pressure
Bypass Valve	Modulates to maintain system differential pressure	Modulates to maintain heat pump differential pressure

Both strategies can work for the refrigerant changeover central geothermal system. Method 1 prioritizes heat pump flow, while method 2 prioritizes system differential pressure control (Figure 38). The base system described in this manual uses Method 1.

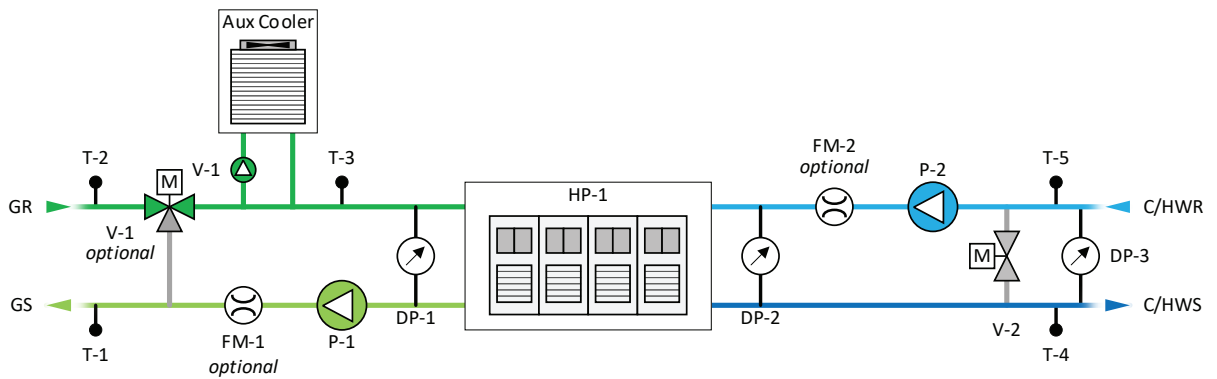
Figure 38. Pump and valve control strategies for refrigerant changeover central geothermal system



Auxiliary Coolers

Auxiliary coolers are typically installed on the ground return line (Figure 39). This ensures that the ground heat exchanger receives the warmest fluid so it can dissipate heat, even when the ground temperature is warm. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary coolers.

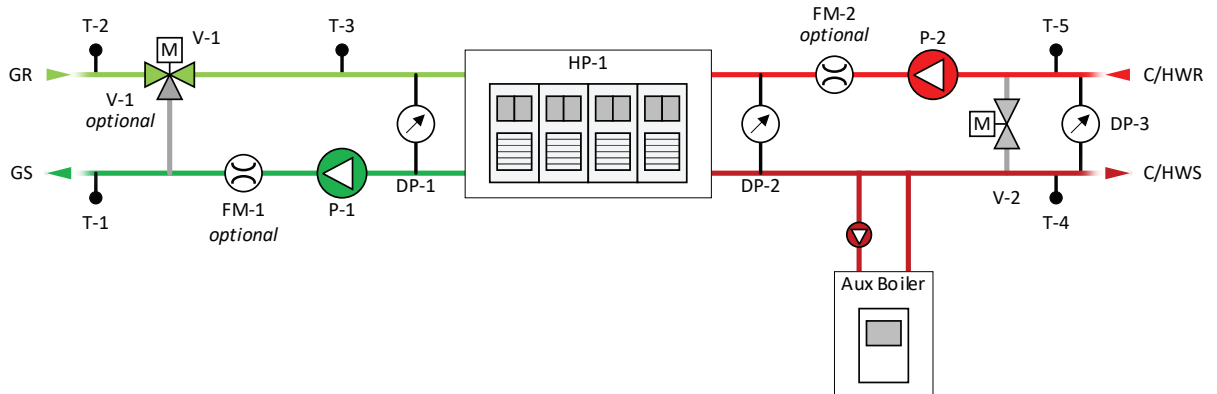
Figure 39. Auxiliary cooler in a refrigerant changeover central geothermal system



Auxiliary Boilers

Auxiliary boilers are typically placed in the heating loop, downstream of the heat pumps (Figure 40). This allows the boiler to supplement the heat pump capacity. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary boilers.

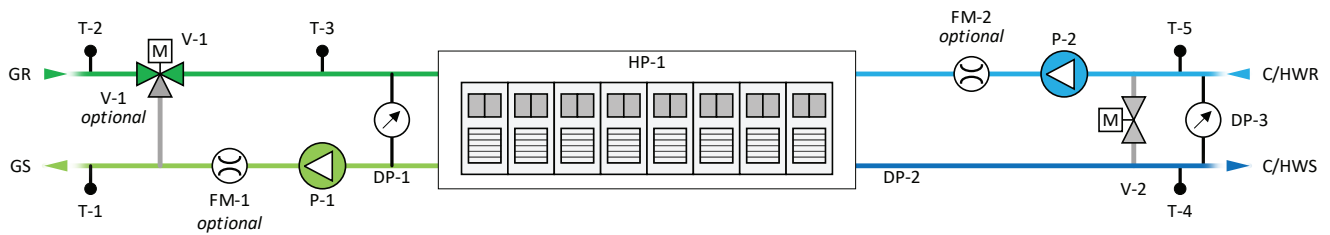
Figure 40. Auxiliary boiler in a refrigerant changeover central geothermal system



Scaling to Higher Capacity

The refrigerant changeover central geothermal system is designed to use modular heat pumps. Modular heat pump banks are scalable by selecting a higher quantity of modules. Modular banks can be selected up to about 1,000 tons (3,517 kW). Multiple banks could be combined for even higher capacity (Figure 41).

Figure 41. Refrigerant changeover central geothermal system with higher quantity of heat pump modules



Hydronic Changeover Central Geothermal System

The hydronic changeover central geothermal system can operate in heating mode or cooling mode (but not at the same time). This system uses packaged heat pumps, which are typically lower cost than modular heat pumps. Packaged heat pumps are also available at higher capacities than modular heat pumps (Figure 42).

System Requirements and Design Considerations

The base configuration of a hydronic changeover central geothermal system has the following attributes (Table 15):

- Non-reversible packaged heat pumps.
- Variable primary flow is used for both the ground loop and the distribution loop.
- A modulating head pressure control valve is included in the ground loop for cooling operation with cold ground temperature.
- Pumps are controlled to a heat pump differential pressure setpoint, corresponding to the pressure drop at design flow value.
- Hydronic changeover results in fluid mixing between the ground loop and the distribution loop. The base design does not include an isolation heat exchanger.
- The base design uses a system controller to manage valve positioning and pump control.

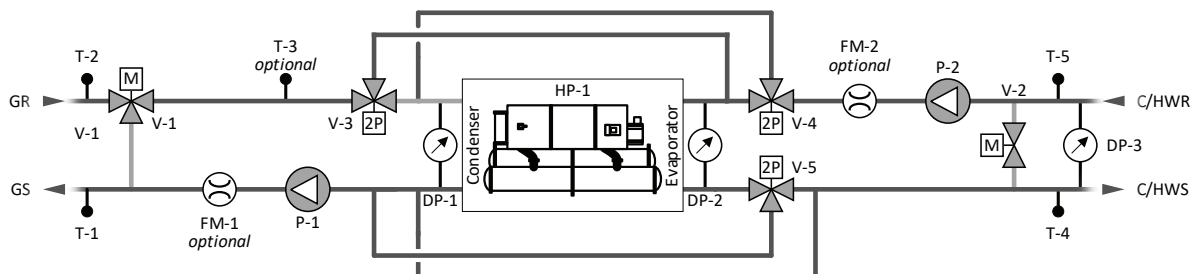
In addition to the base configuration, refer to section "System Options and Alternatives," p. 58, for the following system alternates:

- Pump and flow control strategies
- Auxiliary cooler
- Auxiliary boiler
- Ground loop free cooling
- Alternate changeover valve configurations
- Scaling to higher capacity

The hydronic changeover central geothermal system must comply with ASHRAE 90.1-2022 changeover requirements. Refer to the "Geothermal System Design Considerations," p. 10, section earlier in this manual for additional details.

Component Descriptions

Figure 42. Hydronic changeover geothermal system



Hydronic Changeover Central Geothermal System

Table 15. Component list for hydronic changeover central geothermal system

Component	Description
HP-1	<p>Geothermal heat pump:</p> <ul style="list-style-type: none"> The Geothermal heat pump is a water-to-water heat pump with a non-reversible refrigerant cycle. It can function in heating mode (moving heat from the ground loop to the distribution loop) or in cooling mode (moving heat from the distribution loop to the ground loop). In cooling mode, HP-1 modulates to maintain leaving evaporator temperature and in heating mode, HP-1 modulates to maintain leaving condenser temperature.
P-1	<p>Ground loop pump:</p> <ul style="list-style-type: none"> The ground loop pump provides flow through the ground loop and the geothermal heat pump. In cooling mode, the ground loop pump is connected to the geothermal heat pump condenser. In heating mode, the ground loop pump is connected to the heat pump evaporator. The ground loop pump modulates to maintain differential pressure at the heat pump (DP-1 or DP-2, depending on mode). Optional flow meter FM-1 is used for monitoring and diagnostics—not for pump control.
P-2	<p>Distribution loop pump:</p> <ul style="list-style-type: none"> The distribution loop pump provides flow through the distribution loop and the geothermal heat pump. In cooling mode, the distribution loop pump is connected to the geothermal heat pump evaporator. In heating mode, the distribution loop pumps are connected to the heat pump condenser. The distribution loop pump modulates to maintain differential pressure at the heat pump (DP-2 or DP-1, depending on mode). Optional flow meter FM-2 is used for monitoring and diagnostics, not for pump control.
V-1 (optional)	<p>Ground loop bypass:</p> <p>Ground loop bypass valve is a modulating control valve that provides head pressure control when cooling with low ground temperature. Consult the heat pump manufacturer to determine if this is needed.</p>
V-2	<p>Minimum flow bypass:</p> <ul style="list-style-type: none"> The minimum flow bypass is a modulating control valve, required in variable primary flow systems to maintain a minimum flow rate in the heat pump chillers when distribution flow rate is low. Minimum flow bypass is controlled to the distribution loop differential pressure (DP-3). Bypass valve should be installed near the end of the distribution loop to prevent short loop transit times when the bypass opens. Bypass valve control should be hardwired with a local controller to ensure quick response time.
V-3, V-4, V-5	<p>Hydronic reversing valves:</p> <ul style="list-style-type: none"> Hydronic reversing valves switch the connection of heat pump evaporator and condenser in the system. In cooling mode, the heat pump evaporator is connected to the distribution loop, and the heat pump condenser is connected to the ground loop. In heating mode, the heat pump condenser is connected to the distribution loop, and the heat pump evaporator is connected to the ground loop. Three 3-way valve arrangements are shown. Refer to section "System Options and Alternatives," p. 58, for alternate arrangements.
T1, T2, T3	<p>Ground loop temperature sensors:</p> <p>Ground loop temperature sensors T-1 and T-2 measure the fluid temperature going into and returning from the ground heat exchanger. These temperatures may be used for ground loop flow optimization. Optional temperature sensor T-3 is added when head pressure control valve V-1 is used in the system.</p>
T4, T5	<p>Distribution loop temperature sensors:</p> <p>Distribution loop temperature sensors T-4 and T-5 monitor the heating/cooling fluid temperatures.</p>
DP-1	<p>Heat pump condenser differential pressure sensor:</p> <p>Differential pressure sensor DP-1 monitors fluid differential pressure from across the heat pump condenser.</p>
DP-2	<p>Heat pump evaporator differential pressure sensor:</p> <p>Differential pressure sensor DP-2 monitors fluid differential pressure from across the heat pump evaporator.</p>
DP-3	<p>Distribution loop differential pressure sensor:</p> <p>Differential pressure sensor DP-3 monitors fluid differential pressure at a remote point in the distribution system.</p>
FM-1, FM-2 (optional)	<p>Ground loop and distribution loop flow meters:</p> <p>Flow meter may be added to the ground loop to verify that pump differential pressure control results in the correct flow rate. A mismatch between differential pressure and flow measurements may indicate flow obstructions such as heat exchanger fouling or clogged strainers. Diagnostic warnings may be used to alert operators of potential flow issues.</p>

System Operation and Control

The hydronic changeover central geothermal system responds to a BAS call for heating or cooling. The BAS or a system controller actuates hydronic reversing valves that connect the heat pump condenser and evaporator to the ground loop and distribution loop, depending on the operating mode. Then the BAS issues a temperature setpoint command and operating mode to the heat pump equipment controller. Changeover between heating and cooling modes must comply with ASHRAE 90.1-2022, section 6.5.2.2.2. The hydronic changeover central geothermal system does not provide heat recovery function.

Cooling Mode

In cooling mode, the heat pump evaporator is connected to the distribution loop while the heat pump condenser is connected to the ground loop (Figure 43). The geothermal heat pump modulates capacity to maintain the distribution loop supply temperature. The ground loop pump, distribution loop pump, and minimum flow bypass valve are used to control fluid flow and differential pressure in the system. Head pressure control may be needed in cooling mode when the ground temperature is low (Table 16).

Figure 43. Hydronic changeover geothermal system in cooling mode

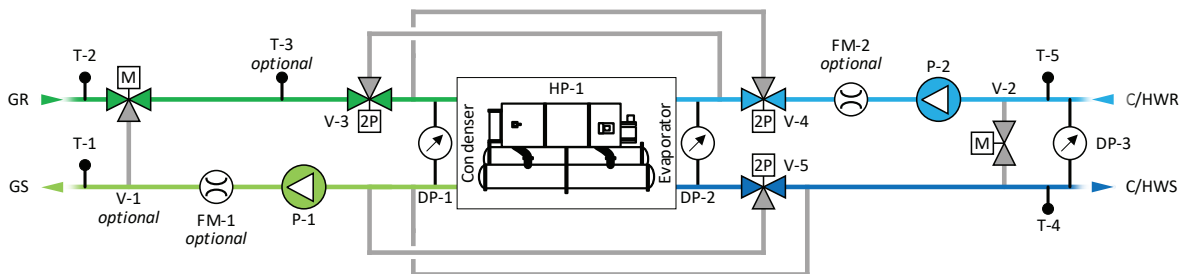


Table 16. Control logic for hydronic changeover central geothermal system in cooling mode

Device	Control Logic	Linked Sensor
HP-1	Modulates to maintain the leaving evaporator temperature at a cooling loop supply setpoint	Sensors in HP-1
P-1	Modulates to maintain heat pump condenser differential pressure	DP-1
P-2	Modulates to maintain heat pump evaporator differential pressure	DP-2
V-1	<ul style="list-style-type: none"> Modulates to maintain minimum head pressure for HP-1 Check with the heat pump manufacturer for minimum head pressure requirements 	Sensor in HP-1, or T-3 and T-4
V-2	Modulates to maintain distribution loop differential pressure	DP-3
V-3, V-4, V-5	<ul style="list-style-type: none"> Ground loop connected to heat pump condenser Distribution loop connected to heat pump evaporator 	N/A

Heating Mode

In heating mode, the heat pump condenser is connected to the distribution loop, while the heat pump evaporator is connected to the ground loop (Figure 44). The geothermal heat pump modulates capacity to maintain the distribution loop supply temperature. The ground loop pump, distribution loop pump, and minimum flow bypass valve are used to control fluid flow and differential pressure in the system (Table 17).

Figure 44. Hydronic changeover geothermal system in heating mode

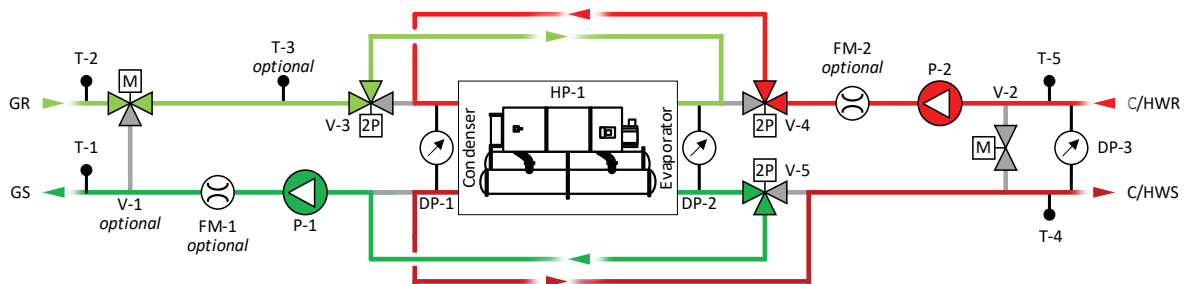


Table 17. Control logic for hydronic changeover central geothermal system in heating mode

Device	Control Logic	Linked Sensor
HP-1	Modulates to maintain the leaving condenser temperature at a heating loop supply setpoint	Sensors in HP-1
P-1	Modulates to maintain heat pump evaporator flow rate	DP-2
P-2	Modulates to maintain heat pump condenser differential pressure	DP-1
V-1 (optional)	Closed <i>Note: V-1 does not require a mode-dependent, forced closure. It will naturally close because head pressure control is not needed.</i>	N/A
V-2	Modulates to maintain distribution loop differential pressure	DP-3
V-3, V-4, V-5	<ul style="list-style-type: none"> Ground loop connected to heat pump evaporator Distribution loop connected to heat pump condenser 	N/A

System Options and Alternatives

Pump and Flow Control

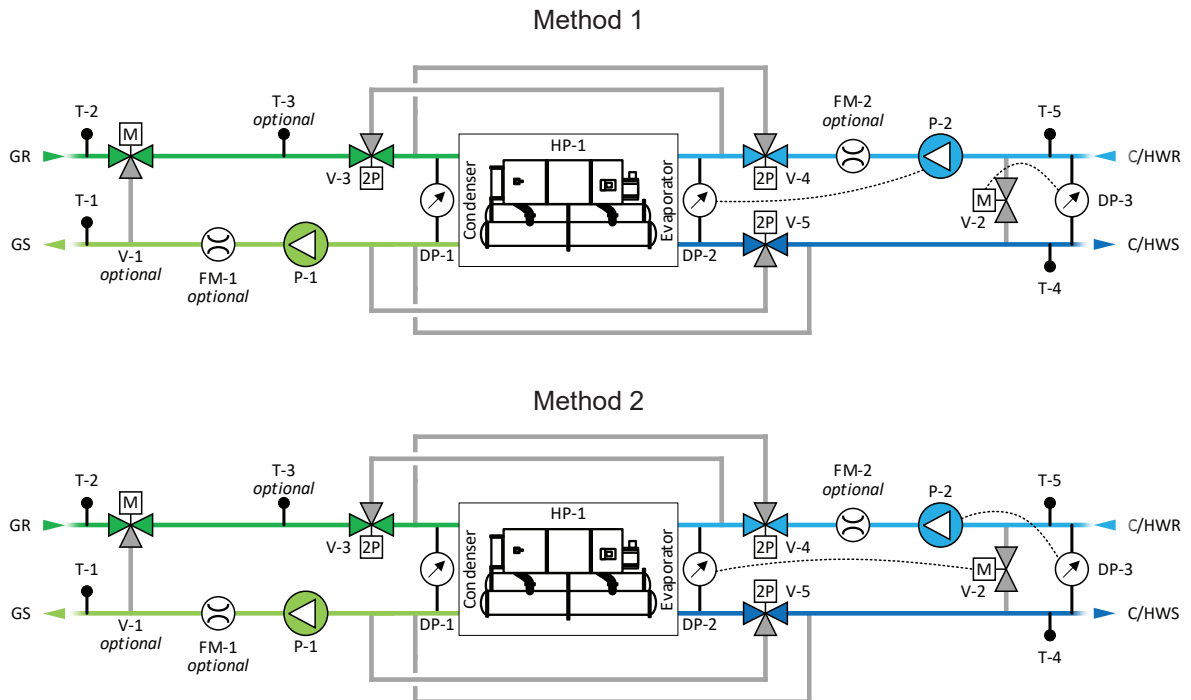
Trane Application Guide PKG-APG001*-EN “Modular Heat Pump Chillers in Variable Primary Flow Hydronic Systems,” describes two methods of controlling the VPF pumps and bypass valves. See [Table 18](#) and [Figure 45](#) for further details.

Note: The hydronic changeover central geothermal system is designed to use packaged heat pumps, not modular heat pumps. Referencing the application guide for variable primary flow with modular heat pump chillers may seem confusing. In practice, either of the control methods described may also be used for packaged heat pumps. For consistency, the base design for each central geothermal system with variable primary flow uses Method 1, although designers may also choose Method 2.

Table 18. Methods of controlling VPF pumps and bypass valves

	Method 1	Method 2
Primary Pumps	Modulates to maintain heat pump differential pressure	Modulates to maintain system differential pressure
Bypass Valve	Modulates to maintain system differential pressure	Modulates to maintain heat pump differential pressure

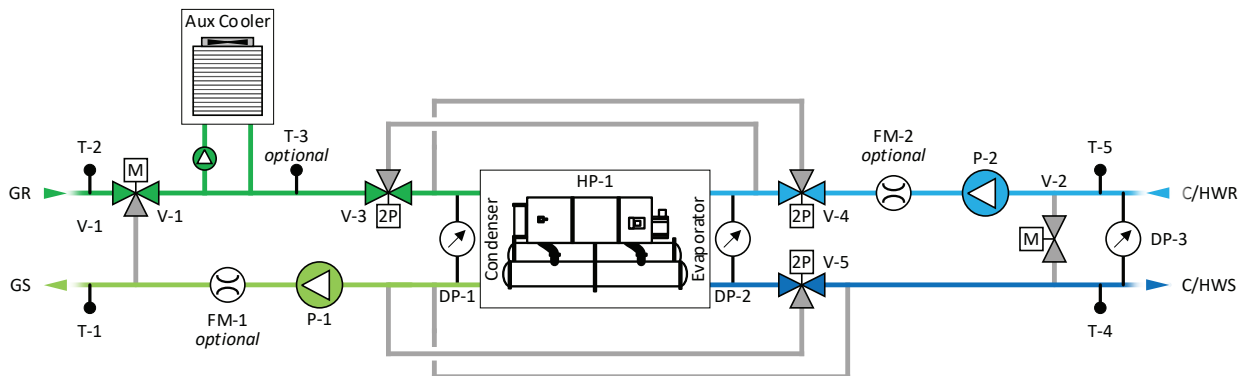
Figure 45. Hydronic changeover central geothermal system with two different flow control strategies



Auxiliary Coolers

Aux coolers are typically installed on the ground return line (Figure 46). This ensures that the ground heat exchanger receives the warmest fluid so it can dissipate heat, even when ground temperature is warm. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary coolers.

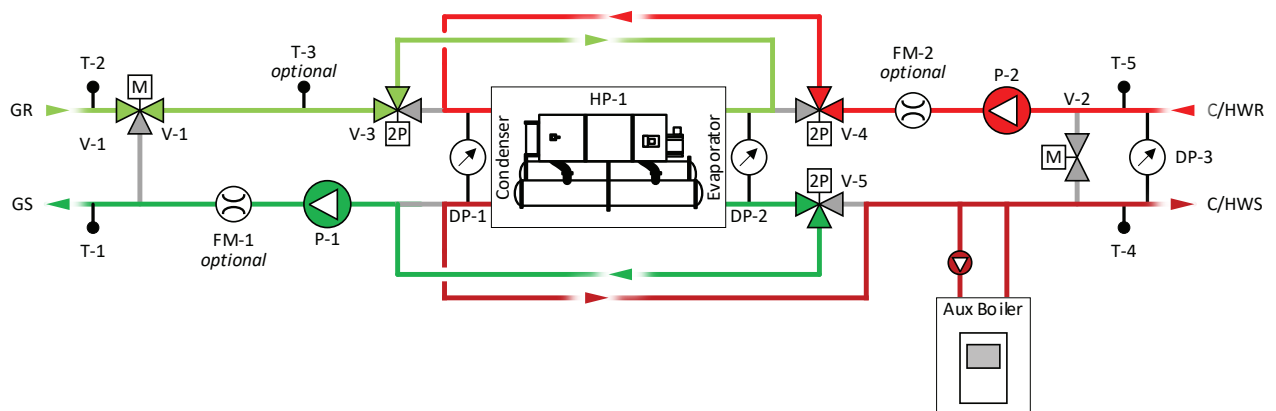
Figure 46. Auxiliary cooler connection in a hydronic changeover central geothermal system



Auxiliary Boilers

Auxiliary boilers are typically placed in the heating loop, downstream of the heat pumps (Figure 47). This allows the boiler to supplement the heat pump capacity. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary boilers.

Figure 47. Auxiliary boiler connection in a hydronic changeover central geothermal system

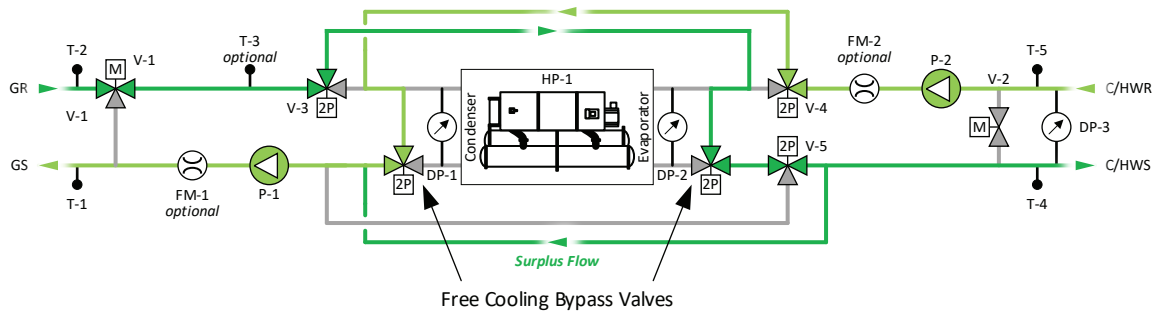


Ground Loop Free Cooling

When ground return temperature is low enough to satisfy the cooling setpoint, the system may run in ground loop free cooling mode (Figure 48).

In ground loop free cooling mode, the ground loop pump P-1 and distribution loop pump P-2 operate in a manner similar to decoupled primary-secondary systems. The pipe between the heat pump leaving condenser and valve V-5 serves as a decoupler. The ground loop flow rate should be controlled higher than the distribution loop flow rate (i.e., surplus flow) to prevent recirculation of the cooling loop return which may elevate the cooling loop supply temperature. Additional free cooling bypass valves may be added to avoid pumping fluid through the heat pump condenser and evaporator when the heat pump is not running.

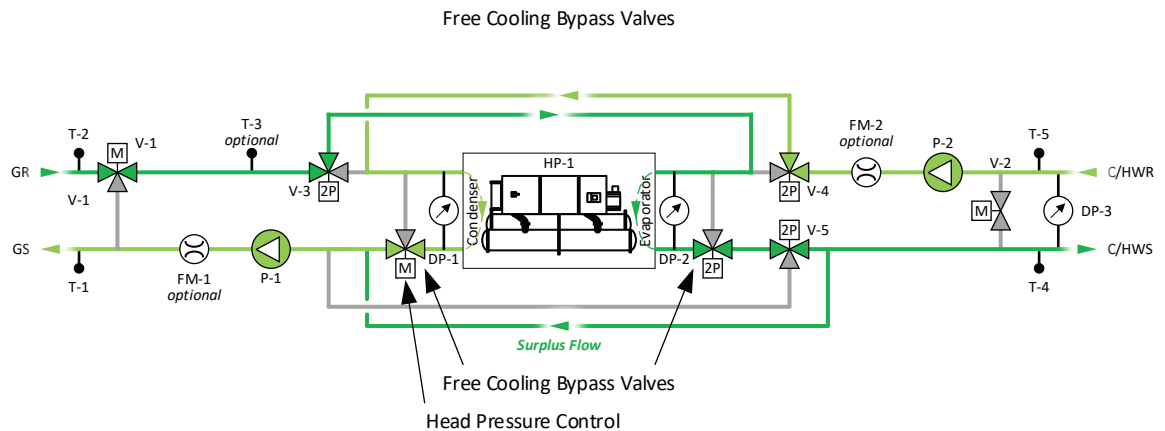
Figure 48. Hydronic changeover geothermal system in ground loop free cooling mode



Hydronic Changeover Central Geothermal System

Partial free cooling may be considered for the hydronic changeover central geothermal system. In partial free cooling, the heat pump provides mechanical cooling to supplement the free cooling capacity from the ground loop (Figure 49). Modulating V-1 for head pressure control elevates the ground return temperature, reducing free cooling capacity. The condenser-side free cooling bypass may be modulated for head pressure control instead of V-1 to maximize free cooling. Partial free cooling is advisable only for systems with a very stable ground return temperature. Designers must ensure that heat rejected by the heat pump condenser does not cause excessive evaporator load. Refer to section "Ground Loop Free Cooling," p. 30, earlier in this manual for additional information on ground loop partial free cooling.

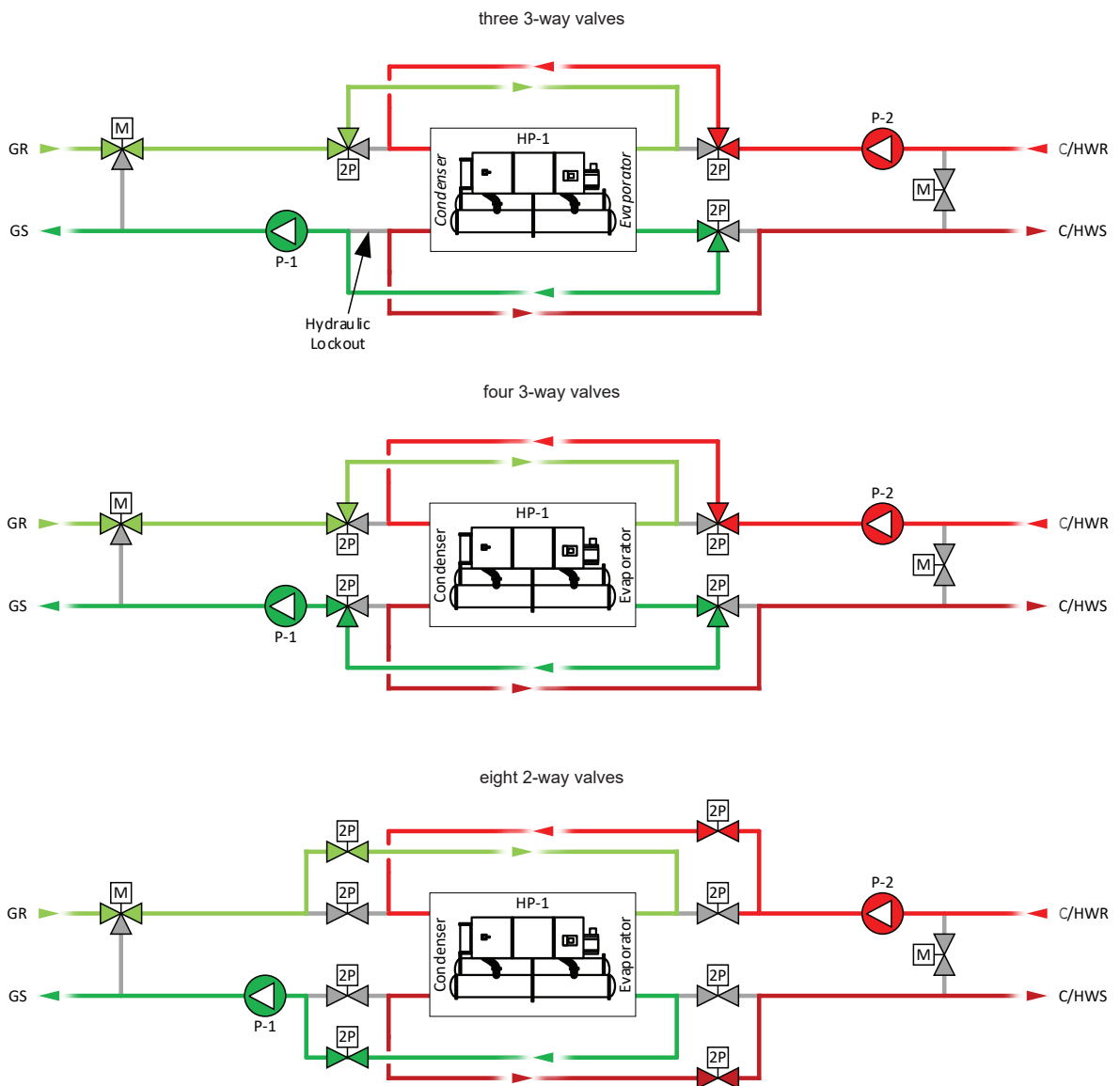
Figure 49. Hydronic changeover central geothermal system in ground loop partial free cooling



Changeover Valve Configurations

Hydronic changeover may be achieved with various valve configurations. The base configuration uses the minimum number of valves and relies on hydraulic lockout on the condenser leaving pipe. Many engineers prefer to add a fourth 3-way valve to positively block flow instead of relying on hydraulic lockouts. Higher capacity systems may require large 3-way valves, which are expensive or hard to source. Each 3-way valve can be replaced with two 2-way valves (Figure 50).

Figure 50. Hydronic changeover valve configurations



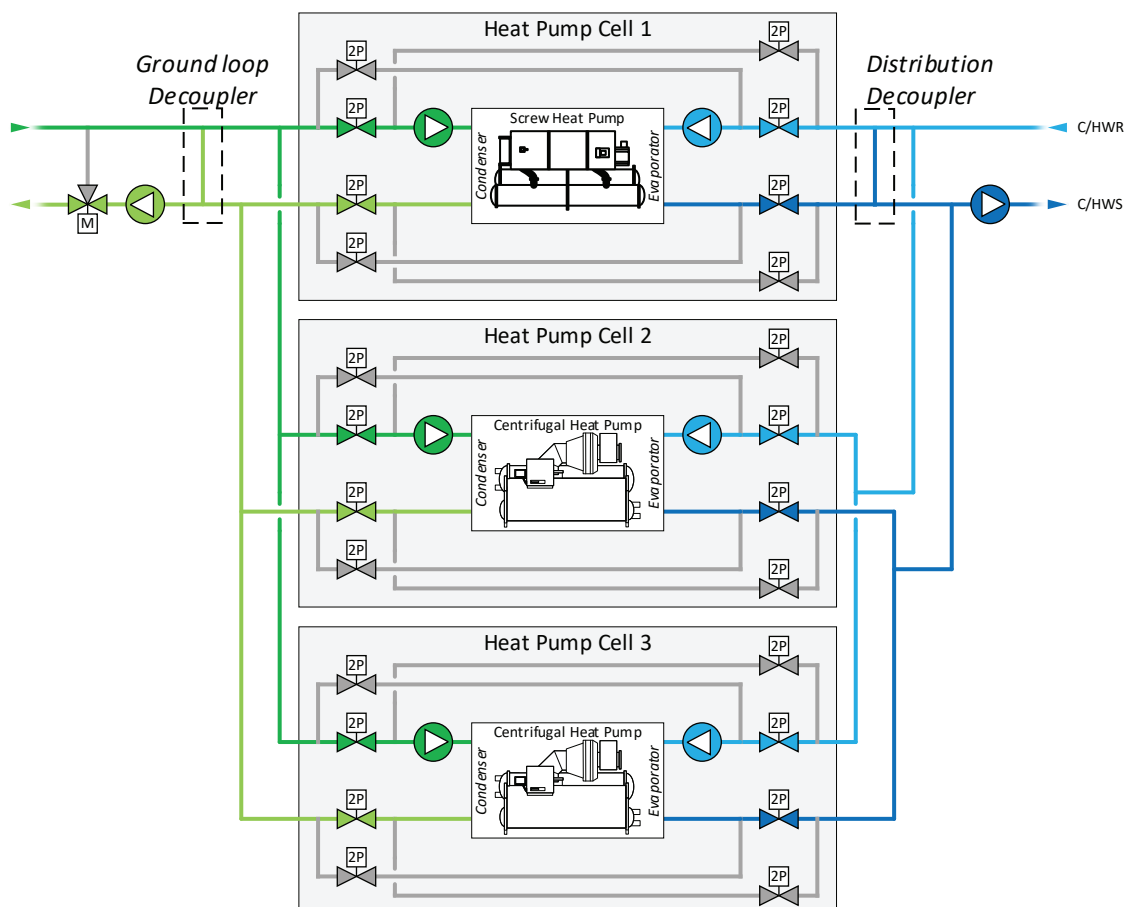
Scaling to Higher Capacity

Hydronic changeover geothermal systems may be scaled to high capacity, for example, over 1,000 tons (3,517 kW). Higher capacity systems should consider centrifugal heat pump chillers for increased capacity and premium efficiency.

Large scale geothermal systems are likely to be used for district energy systems, campus loops, or very large buildings. Decoupled primary-secondary pumping may be preferred to separate the distribution pump control from the chiller flow management (Figure 51). By placing primary pumps between the changeover valves and the heat pumps, each pump is dedicated to one heat exchanger instead of switching between the evaporator and condenser. This may simplify pump control in different operating modes.

Compressor turndown must be considered with centrifugal heat pumps to avoid compressor surge. One strategy is to include a smaller heat pump that can unload to a lower capacity than a large centrifugal heat pump. Preferential piping allows the centrifugal heat pumps to load immediately once enabled. Screw compressor heat pumps are a good choice for the smaller heat pump.

Figure 51. High-capacity changeover geothermal system with two centrifugal heat pumps positioned for preferential loading.



Modular Multi-pipe Central Geothermal System

The modular multi-pipe central geothermal system provides simultaneous heating and cooling capabilities. It also includes a built-in heat recovery function for improved system efficiency. This system takes advantage of modular multi-pipe heat pumps (i.e., 6-pipe heat pumps) to simplify the system design (Figure 52).

System Requirements and Design Considerations

The base configuration of the modular multi-pipe central geothermal system has the following attributes (Table 19, p. 65):

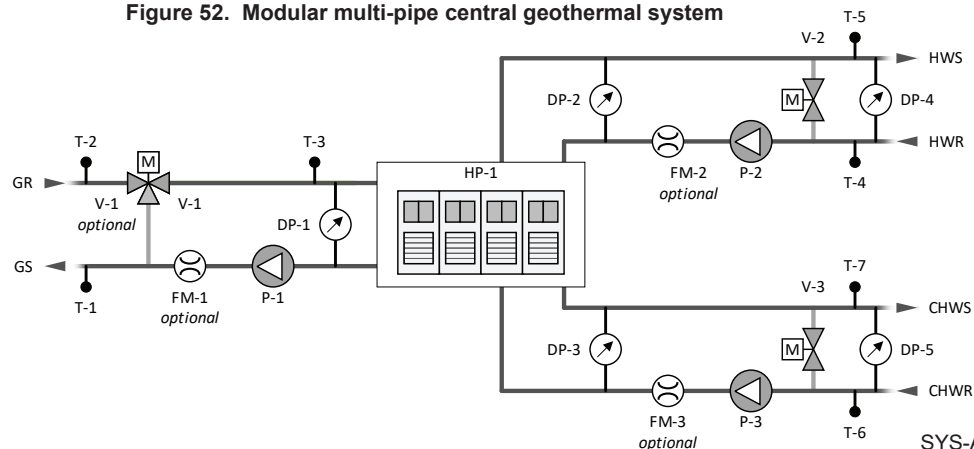
- Modular multi-pipe heat pumps have integral valves in the refrigerant circuit that change operation of each module between heating mode, cooling mode, and simultaneous heating and cooling mode (heat recovery).
- The modular bank controller coordinates valve position and compressor staging needed to regulate the supply temperatures of both the cooling loop and heating loop.
- Variable primary flow is used for the ground loop, cooling loop, and heating loop. Decoupled primary-secondary pumping could also be used.
 - Modular heat pumps are assumed to include internal flow control valves (closed to isolate flow in modules that are not running). This creates a stepped variable flow in the system.
- An optional head pressure control valve V-1 is shown for systems that operate in cooling mode with a low ground return temperature. Many modular chillers have internal head pressure control (by modulating the flow isolation valves on the condenser side).
- Pumps are controlled to maintain design differential pressure across each heat exchanger of the multi-pipe heat pump,
- The base design assumes that fluids in the ground loop, cooling loop, and heating loop are all isolated. Designers should confirm this assumption with the heat pump manufacturer.

In addition to the base configuration, refer to section "System Options and Alternatives," p. 69, for more about the following system alternatives:

- Pump and flow control strategies
- Auxiliary cooler
- Auxiliary boiler
- Scaling to higher capacity

Component Descriptions

Figure 52. Modular multi-pipe central geothermal system



Modular Multi-pipe Central Geothermal System

Table 19. Components list for modular multi-pipe central geothermal system

Component	Description
HP-1	<p>Geothermal heat pump:</p> <ul style="list-style-type: none"> The geothermal heat pump is a modular multi-pipe heat pump with integral refrigerant valves that allow operation in heating mode, cooling mode, and simultaneous heating and cooling mode. The modular multi-pipe heat pump receives an enable signal, cooling setpoint, and heating setpoint from BAS. The heat pump controller modulates compressor staging and refrigerant valve position to maintain heating and cooling fluid temperatures.
P-1	<p>Ground loop pump:</p> <ul style="list-style-type: none"> The ground loop pump provides flow through the ground loop and geothermal heat pump. The ground loop pump controls differential pressure at the heat pump (DP-1). Optional flow meter FM-1 is used for monitoring and diagnostics, not for pump control.
P-2	<p>Heating loop pump:</p> <ul style="list-style-type: none"> The heating loop pump provides flow to the heating loop and the heat pump condenser. The heating loop pump controls differential pressure at the heat pump condenser (DP-2). Optional flow meter FM-2 is used for monitoring and diagnostics, not for pump control.
P-3	<p>Cooling loop pump:</p> <ul style="list-style-type: none"> The cooling loop pump provides flow to the cooling loop and the heat pump evaporator. The cooling loop pumps controls differential pressure at the heat pump evaporator (DP-3). Optional flow meter FM-3 is used for monitoring and diagnostics, not for pump control.
V-1 (optional)	<p>Ground loop bypass:</p> <p>Ground loop bypass valve is a modulating control valve that provides head pressure control when cooling with low ground temperature. Consult the heat pump manufacturer to determine if external head pressure is needed.</p>
V-2, V-3	<p>Minimum flow bypass:</p> <ul style="list-style-type: none"> A minimum flow bypass is required in variable primary flow systems to maintain a minimum flow rate in the heat pump when distribution flow rate is low. Minimum flow bypass is controlled to the distribution loop differential pressure (DP-4 for the heating loop and DP-5 for the cooling loop). Bypass valve should be installed near the end of the distribution loops to prevent short loop transit times when the bypass opens. Bypass valve control should be hardwired with a local controller to ensure quick response time.
T1, T2, T3	<p>Ground loop temperature sensors:</p> <ul style="list-style-type: none"> Ground loop temperature sensors T-1 and T-2 measure the fluid temperature going into and returning from the ground heat exchanger. These temperatures may be used for ground loop flow optimization. Optional temperature sensor T-3 is added when head pressure control valve V-1 is used in the system.
T4, T5, T6, T7	<p>Distribution loop temperature sensors:</p> <p>Distribution loop temperature sensors T-4, T-5, T-6, and T-7 monitor fluid temperatures in the heating loop and cooling loop.</p>
DP-1, DP-2, DP-3	<p>Heat pump ground loop differential pressure sensors:</p> <p>Differential pressure sensor DP-1, DP-2, and DP-3 monitor fluid differential pressure across each heat exchanger of the multi-pipe heat pump. DP-1 is installed on the ground loop, DP-2 is installed on the condenser, and DP-3 is installed on the evaporator. These differential pressure sensors are used for pump speed control.</p>
DP-4, DP-5	<p>Distribution loop differential pressure sensors:</p> <p>Differential pressure sensors DP-4 and DP-5 monitor fluid pressure at a remote point in the distribution system. These differential pressure sensors are used to control minimum flow bypass valves V-2 and V-3.</p>
FM-1, FM-2, FM-3 (optional)	<p>Ground loop and distribution loop flow meters:</p> <p>Flow meter may be added to the ground loop to verify that pump differential pressure control results in the correct flow rate. A mismatch between differential pressure and flow measurements may indicate flow obstructions such as heat exchanger fouling or clogged strainers. Diagnostic warnings may be used to alert operators of potential flow issues.</p>

System Operation and Control

The modular multi-pipe heat pump responds to a BAS call for heating and/or cooling. The BAS enables the heat pump and issues both heating and cooling setpoint temperatures. The modular multi-pipe heat pump controller actuates the valves in the heat pump and stages the compressors on and off as needed to achieve the specified heating and cooling setpoint temperatures.

Cooling-Only Mode

In cooling mode, the system controller enables ground loop pumps and the cooling loop pumps (Figure 53). The heating loop pumps are disabled. HP-1 stages modules as needed to maintain the cooling loop supply temperature. See Table 20 for more details.

Figure 53. Modular multi-pipe central geothermal system in cooling-only mode

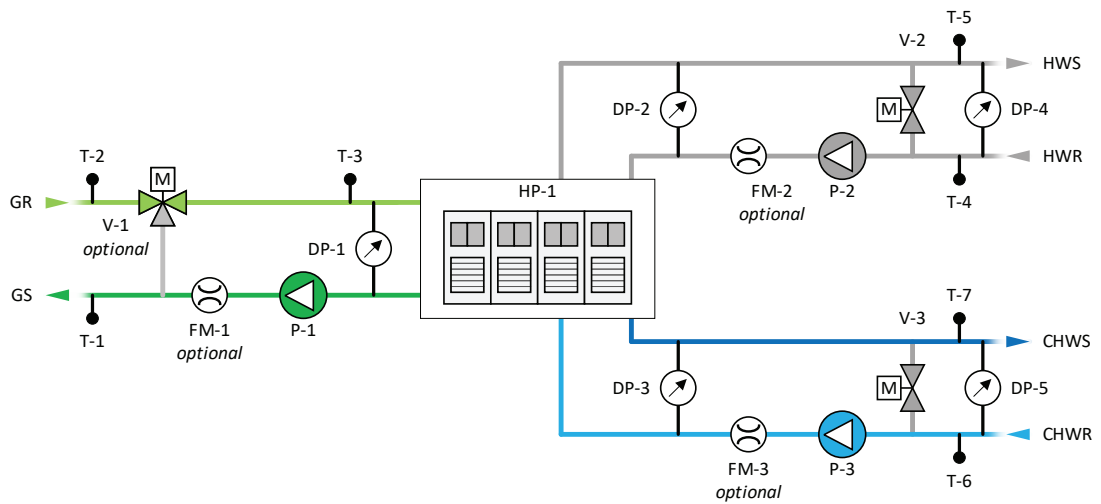


Table 20. Control logic for modular multi-pipe geothermal system in cooling-only mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain leaving evaporator temperature	Sensor in HP-1
P-1	Modulates to maintain heat pump ground loop differential pressure	DP-1
P-2	Off	N/A
P-3	Modulates to maintain heat pump evaporator differential pressure	DP-3
V-1 (optional)	<ul style="list-style-type: none"> Modulates to maintain minimum head pressure for HP-1 Check with the heat pump manufacturer for minimum head pressure requirements 	Sensor in HP-1, or T-3 and T-7
V-2	Closed	N/A
V-3	Modulates to maintain cooling distribution pressure	DP-5

Heating-Only Mode

In heating mode, the system controller enables ground loop pumps and heating loop pumps (Figure 54). The cooling loop pumps are disabled. HP-1 stages modules as needed to maintain the heating loop supply temperature (Table 21).

Figure 54. Modular multi-pipe central geothermal system in heating-only mode

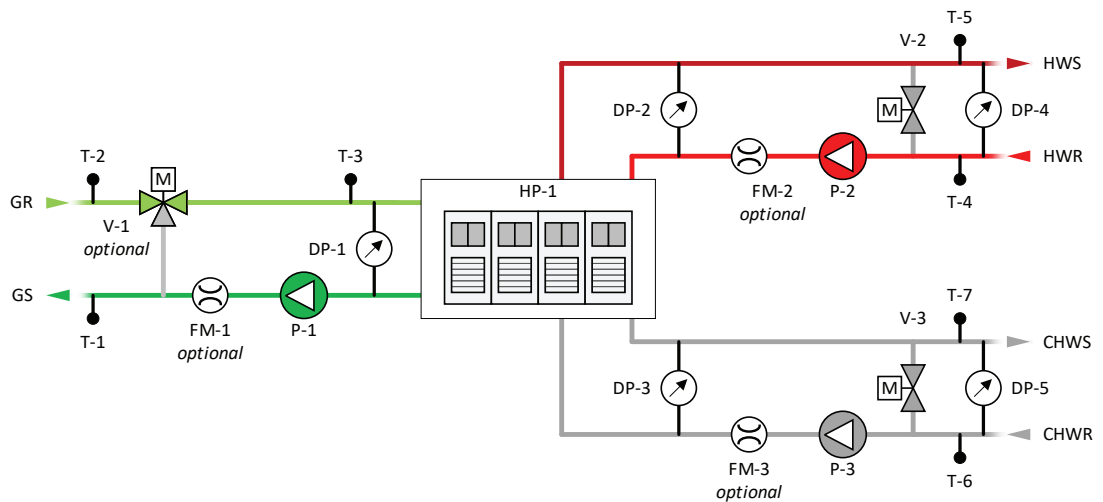


Table 21. Control logic for modular multi-pipe geothermal system in heating-only mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain leaving condenser temperature	Sensor in HP-1
P-1	Modulates to maintain heat pump ground loop differential pressure	DP-1
P-2	Modulates to maintain heat pump condenser differential pressure	DP-2
P-3	Off	N/A
V-1 (optional)	Closed <i>Note: V-1 does not require a mode-dependent, forced closure. It will naturally close because head pressure control is not needed.</i>	N/A
V-2	Modulates to maintain heating loop distribution pressure	DP-4
V-3	Closed	N/A

Simultaneous Heating and Cooling

In simultaneous heating and cooling mode, the system controller enables pumps in the ground loop, cooling loop, and heating loop (Figure 55). HP-1 stages modules as needed to maintain both the heating loop and cooling loop supply temperatures. The system controller does not need to adjust the system configuration for heating dominant or cooling dominant operation, so no distinction is made between the two here (Table 22).

Figure 55. Modular multi-pipe central geothermal system in heating dominant mode

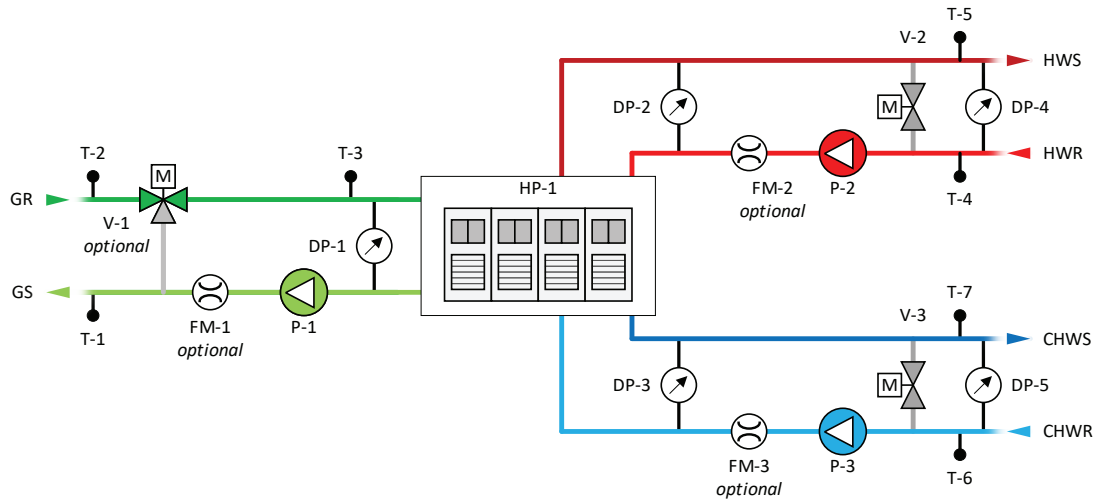


Table 22. Control logic for modular multi-pipe geothermal system in simultaneous heating and cooling mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain leaving evaporator temperature and leaving condenser temperature	Sensor in HP-1
P-1	Modulates to maintain heat pump ground loop differential pressure	DP-1
P-2	Modulates to maintain heat pump condenser differential pressure	DP-2
P-3	Modulates to maintain heat pump evaporator differential pressure	DP-3
V-1 (optional)	<ul style="list-style-type: none"> Modulates to maintain minimum head pressure for HP-1 Check with the heat pump manufacturer for minimum head pressure requirements 	Sensor in HP-1, or T-3 and T-7
V-2	Modulates to maintain heating loop distribution pressure	DP-4
V-3	Modulates to maintain cooling loop distribution pressure	DP-5

System Options and Alternatives

Pump and Flow Control

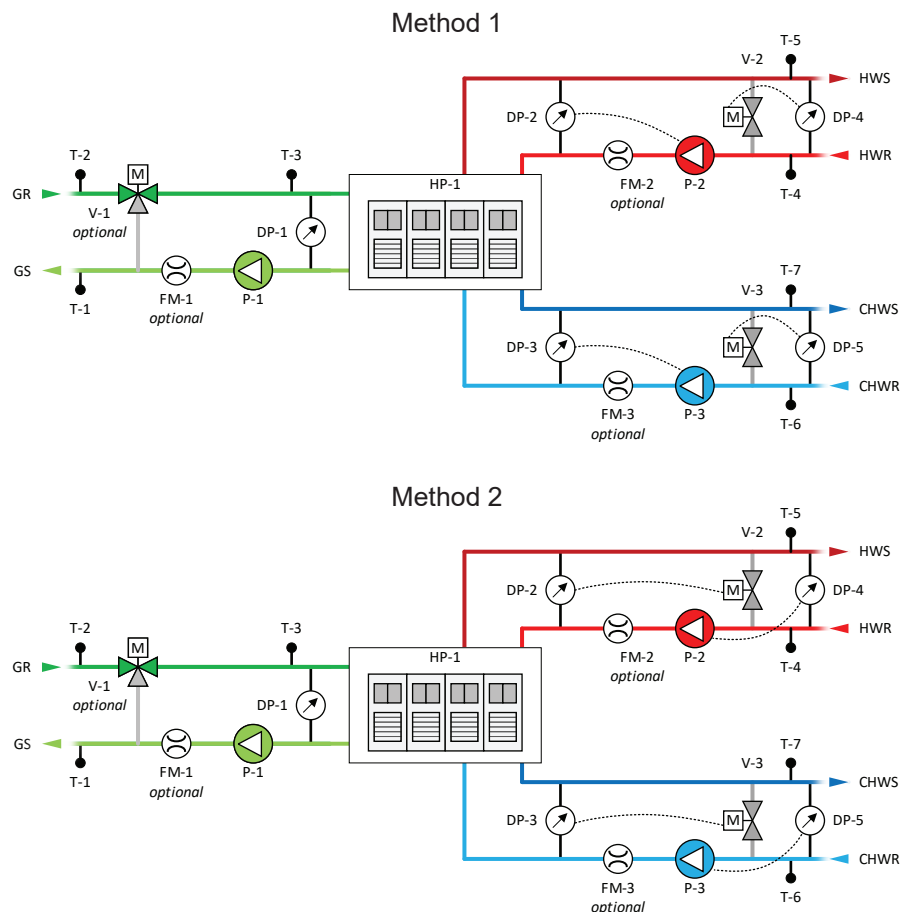
Trane Application Guide PKG-APG001*-EN “Modular Heat Pump Chillers in Variable Primary Flow Hydronic Systems” describes two methods of controlling the VPF pumps and bypass valves (Table 23).

Table 23. Methods of controlling VPF pumps and bypass valves

	Method 1	Method 2
Primary Pumps	Modulates to maintain heat pump differential pressure	Modulates to maintain system differential pressure
Bypass Valve	Modulates to maintain system differential pressure	Modulates to maintain heat pump differential pressure

Both strategies can work for the modular multi-pipe central geothermal system. Method 1 prioritizes heat pump flow while method 2 prioritizes system differential pressure control (Figure 56). The base system described in this manual uses method 1.

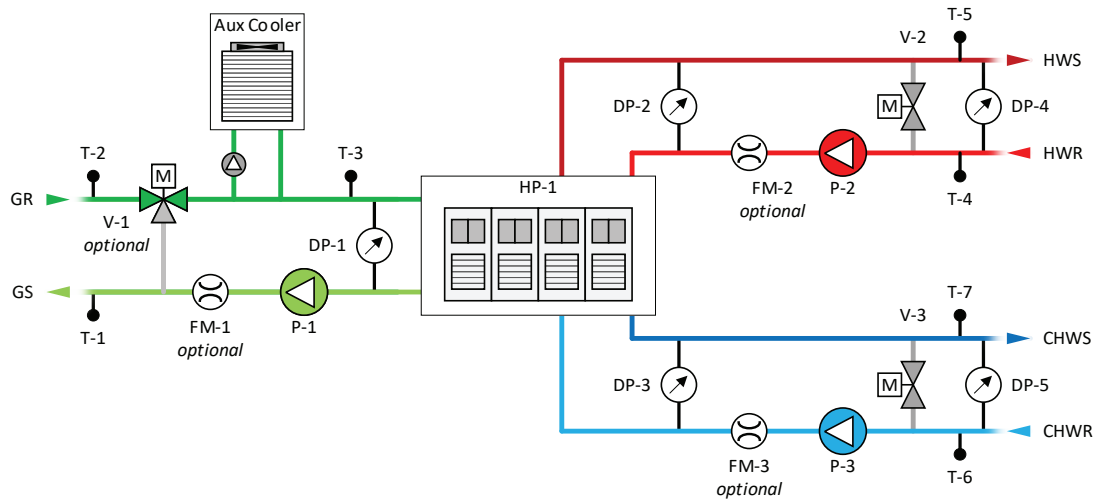
Figure 56. Pump and valve control strategies for modular multi-pipe central geothermal system



Auxiliary Coolers

Auxiliary coolers are typically installed on the ground return line (Figure 57). This ensures that the ground heat exchanger receives the warmest fluid and therefore has the opportunity to dissipate heat, even when the ground temperature is warm. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary coolers.

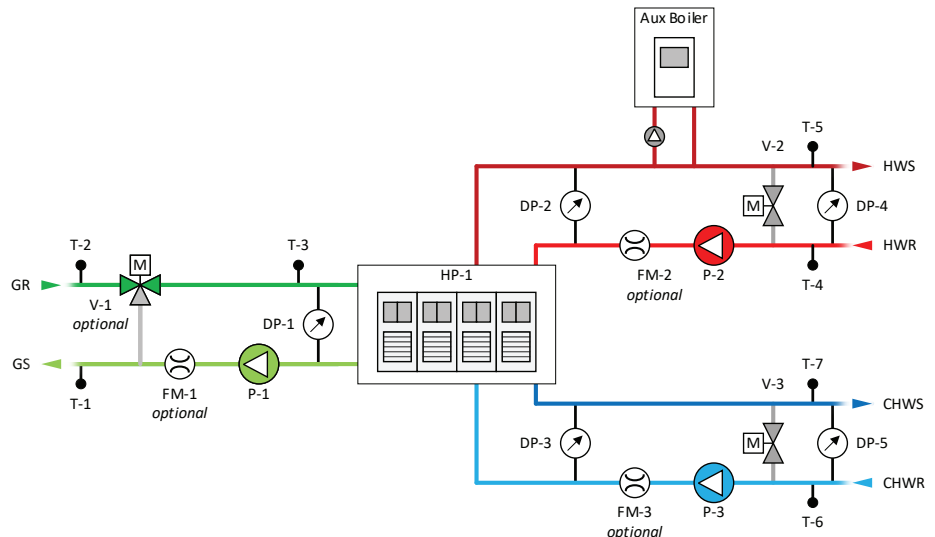
Figure 57. Auxiliary cooler in a modular multi-pipe central geothermal system



Auxiliary Boilers

Auxiliary boilers are typically placed in the heating loop, downstream of the heat pumps (Figure 58). This allows the boiler to supplement the heat pump capacity. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary boilers.

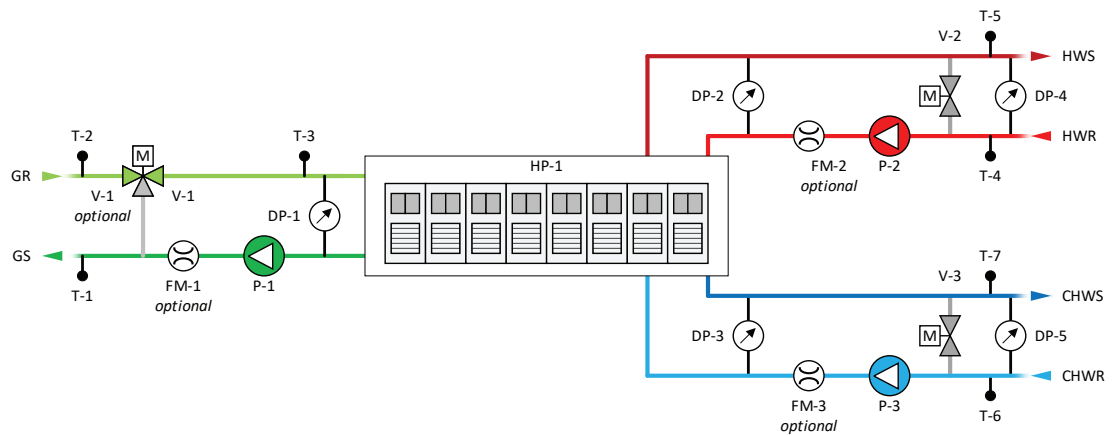
Figure 58. Auxiliary boiler in a modular multi-pipe central geothermal system



Scaling to Higher Capacity

The modular multi-pipe central geothermal system is designed to use modular heat pumps (Figure 59). Modular heat pump banks are scalable by selecting a higher quality of modules. Modular multi-pipe banks can be selected for up to about 600 tons (2,110 kW). Multiple banks can be combined for even higher capacity.

Figure 59. Modular multi-pipe central geothermal system with higher quantity of heat pump modules



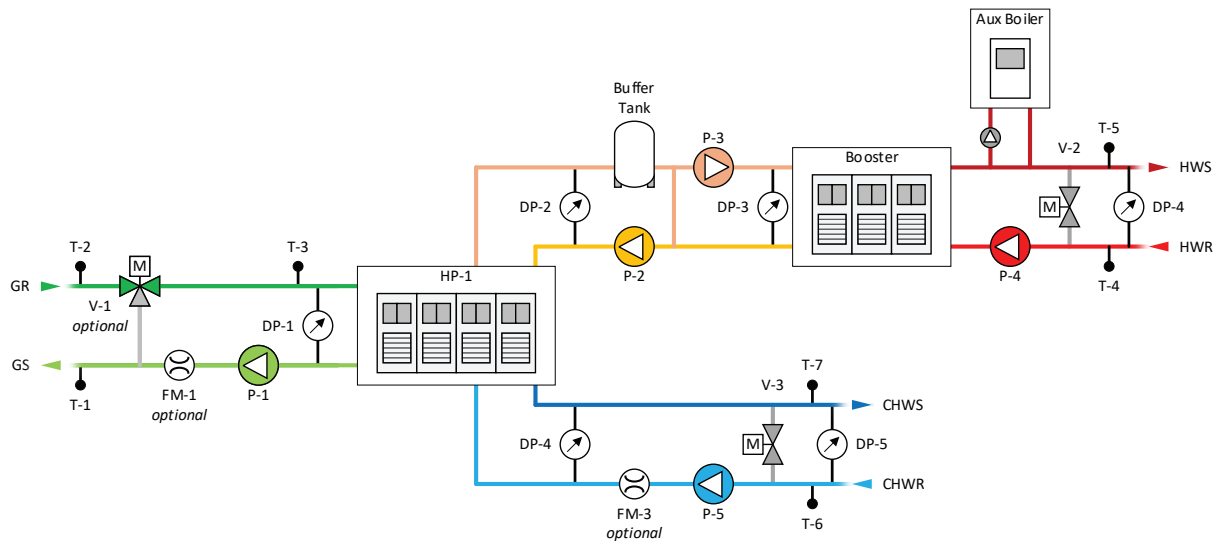
Cascading for Higher Temperature Heating

Most geothermal systems are designed with high efficiency in mind. The selection of the heating fluid temperature plays a major role in achieving premium system efficiency. High-temperature heating results in high compressor lift, especially when the ground loop return temperature is low.

High heating temperatures also affect heat pump selection. One solution to improve the system operating map is the use of cascaded heat pumps, also known as booster heat pumps. In cascade systems, the condenser of one unit feeds the evaporator of the next (Figure 60).

The "System Options and Alternatives," p. 100, section for parallel central geothermal systems includes design strategies for applying high-temperature booster heat pumps. The example system below illustrates a booster heat pump added to a modular multi-pipe central geothermal system.

Figure 60. Modular multi-pipe central geothermal system with high temperature booster



Blended Loop Central Geothermal System

The blended loop central geothermal system is designed to provide simultaneous heating and cooling, with flexibility to operate in heating-only or cooling-only modes (Figure 61, p. 74). This system provides a lower cost alternative to the modular multi-pipe central geothermal system. The blended loop central geothermal system is best suited for central plants between 100 tons and 300 tons (between 352 kW and 1,055 kW). Designers should consider the parallel central geothermal system for projects that require capacity over 300 tons (1,055 kW).

System Requirements and Design Considerations

The base configuration of the blended loop central geothermal system has the following attributes (Table 24, p. 75):

- A single non-reversible, packaged heat pump is used.
 - Refer to section "System Options and Alternatives," p. 81, for an example of a higher capacity system with two heat pumps.
- The heat pump is connected in a heat recovery manner (between the cooling loop and heating loop). The ground loop is used to balance thermal energy in the system—sourcing heat in heating dominant conditions and rejecting heat in cooling dominant conditions.
 - The ground loop is blended with the smaller (non-dominant) load. Some call this method of operation "false loading."
- The base design connects the ground loop to the heating loop return and cooling loop supply. The ground loop connection point affects the allowable range of ground loop return temperature. Alternative connection methods are included in the "System Options and Alternatives," p. 81, section that allow designers to optimize the system for the expected range of ground temperatures.
- The base configuration uses decoupled primary-secondary pumping for the heating loop and cooling loop. This makes the system simpler to control compared to using variable primary flow. Refer to section "System Options and Alternatives," p. 81, for a variable primary flow alternative.
- A single two-position 3-way valve is used to switch the connection of the ground loop between the condenser loop (for cooling dominant operation) and the evaporator loop (for heating dominant operation).

In addition to the base configuration, refer to section "System Options and Alternatives," p. 81, for an explanation of the following system alternates.

- Variable primary flow
- Auxiliary coolers
- Auxiliary boilers
- Ground loop free cooling
- Scaling to higher capacity
- Optimizing for borefield operating temperature range

Component Descriptions

Figure 61. Blended loop central geothermal system

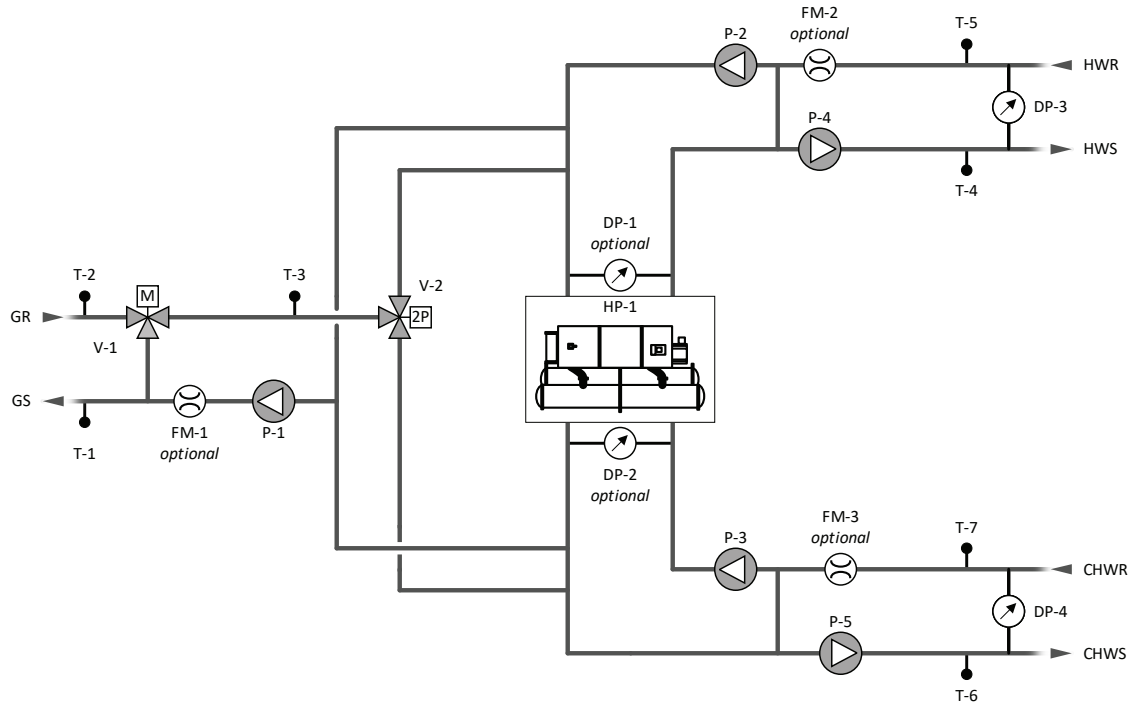


Table 24. Components list for blended loop central geothermal system

Component	Description
HP-1	<p>Geothermal heat pump:</p> <ul style="list-style-type: none"> The geothermal heat pump is a water-to-water heat pump with non-reversible refrigeration cycle. The geothermal heat pump is capable of regulating the leaving evaporator temperature (cooling priority) or the leaving condenser temperature (heating priority). The geothermal heat pump operates in heating mode, cooling, mode, or simultaneous heating and cooling mode, depending on position of valves in the system.
P-1	<p>Ground loop pump:</p> <ul style="list-style-type: none"> The ground loop pump provides flow through the ground loop. The ground loop must have a wide range of modulation in order to regulate heating or cooling supply temperatures (depending on operating mode). Ground loop bypass valve V-1 provides a second stage of modulation when pump P-1 is at minimum speed.
P-2	<p>Condenser loop primary pump:</p> <p>The condenser loop primary pump controls flow in heat pump condenser loop. The condenser loop primary pump speed is modulated for head pressure control in cooling mode with cold ground return temperature. If P-2 is a fixed speed pump, head pressure control may also be achieved by modulating P-1, V-1 or by installing a throttling valve in the condenser loop</p>
P-3	<p>Evaporator loop primary pump:</p> <p>The evaporator loop primary pump controls flow in heat pump evaporator loop. Since the evaporator loop is a constant flow primary, a fixed speed pump may be selected. Alternately, a VFD may be used to balance flow at commissioning with a fixed speed setpoint used in operation.</p>
P-4	<p>Heating loop distribution pump:</p> <p>The heating loop distribution pump provides flow to the heating loop. The heating loop pump is controlled to distribution supply pressure DP-3.</p>
P-5	<p>Cooling loop distribution pump:</p> <p>The cooling loop distribution pump provides flow to the cooling loop. The cooling loop pump is controlled to distribution supply pressure DP-4.</p>
V-1	<p>Ground loop bypass:</p> <p>The ground loop bypass is a modulating control valve that provides stage 2 modulation of ground loop capacity when pump P-1 is at minimum speed</p>
V-2	<p>Ground loop mode control valve:</p> <p>The ground loop mode control valve is a two-position valve that directs ground loop flow to either the heat pump condenser loop or the heat pump evaporator loop, depending on system operating mode.</p> <ul style="list-style-type: none"> Ground flow is directed to the condenser for cooling-only or cooling dominant modes. Ground flow is directed to the evaporator for heating-only, heating dominant, or ground loop free cooling modes.
T-1, T-2, T-3	<p>Ground loop temperature sensors:</p> <p>Ground loop temperature sensors T-1 and T-2 measure the fluid temperature going into and returning from the ground heat exchanger. These temperatures may be used for ground loop flow optimization. T-3 is used when bypass valve V-1 is modulating.</p>
T-4, T-5, T-6, T-7	<p>Distribution loop temperature sensors:</p> <p>Distribution loop temperature sensors T-4 and T-5 monitor the heating loop operating temperatures. Sensors T-6 and T-7 monitor the cooling loop operating temperatures.</p>
DP-1, DP-2 (optional)	<p>Heat pump differential pressure sensors:</p> <p>Since the heat pump operates at constant flow, the primary pumps P-2 and P-3 may operate at fixed speed (either non-VFD at 60Hz, or with a VFD set to a fixed speed value determined at commissioning). Differential pressure sensors are not required for pump flow control but may be included for system monitoring and diagnostics.</p>
DP-3	<p>Heating loop differential pressure sensor:</p> <p>Differential pressure sensor DP-3 monitors fluid pressure at a remote point in the heating distribution system. DP-3 is used to control the heating loop distribution pump P-4.</p>
DP-4	<p>Cooling loop differential pressure sensor:</p> <p>Differential pressure sensor DP-4 monitors fluid pressure at a remote point in the cooling loop. DP-4 is used to control the cooling loop distribution pump P-5.</p>

System Operation and Control

The blended loop central geothermal system responds to a BAS call for cooling, heating, or both. When the system requires heating **or** cooling only, the heat pump regulates the distribution supply temperature. When the system requires simultaneous heating **and** cooling, the system must coordinate the operation of the heat pump and the ground loop to achieve regulation of two different supply temperatures. [Table 25](#) summarizes the control strategy for the blended loop central geothermal system.

Table 25. Temperature control strategy for blended loop central geothermal system

	Cooling loop temperature	Heating loop temperature	Ground loop temperature
Cooling-only mode	Controlled by heat pump	Off	
Heating-only mode	Off	Controlled by heat pump	Uncontrolled, follows ground temperature
Simultaneous mode, cooling dominant	Controlled by heat pump	Controlled by ground loop flow	
Simultaneous mode, heating dominant	Controlled by ground loop flow	Controlled by heat pump	

When the system operates in simultaneous heating and cooling, the BAS must determine whether the system is heating dominant or cooling dominant. The following strategies may be used:

- Outdoor air temperature (OAT) may be used for many buildings. The threshold is set for the balance point temperature of the building (the OAT that results in equal heating and cooling loads). When OAT is below the threshold, the system is assumed to be heating dominant; when OAT is above the threshold, the system is assumed to be cooling dominant.
- Btu meters provide a more precise and real-time measurement of load demand in the heating loop and cooling loop. Flow meters and temperature sensors may also be used to calculate Btu.

Note: Heat pump condenser capacity is greater than the evaporator capacity due to the heat of compression. The shift between heating dominant and cooling dominant conditions happens when the evaporator and condenser capacities are balanced, not when the heating and cooling loads are equal. Balance is typically achieved when condenser capacity is approximately 1.3 times the evaporator capacity. The exact ratio between evaporator and condenser capacity may be calculated from the heat pump performance data.

Cooling-Only Mode

In cooling-only mode, the geothermal heat pump operates to control the cooling loop supply temperature. The heating loop is off, and the system does not need to control heating loop supply temperature. The ground loop is connected to the heat pump condenser (Figure 62). Ground loop temperature “floats” based on the temperature in the ground heat exchanger. This improves compressor efficiency compared to simultaneous heating and cooling mode due to reduced compressor lift. Ground loop flow rate may be controlled (Table 26) to an optimal temperature differential value (refer to section “Ground Loop Pump Energy,” p. 31, for more information).

Figure 62. Blended loop central geothermal system in cooling-only mode

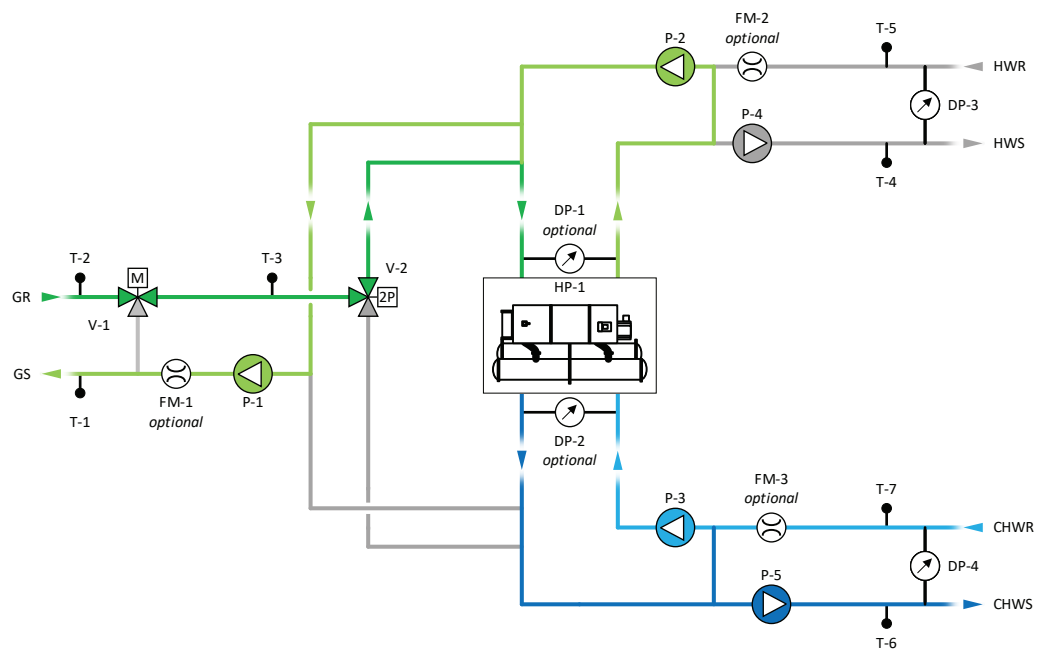


Table 26. Control logic for blended loop central geothermal system in cooling-only mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain the leaving evaporator temperature at a cooling loop supply setpoint	Sensor in HP-1
P-1	Modulates to maintain ground loop temperature at an optimal delta T setpoint	T-1, T-2
P-2	<ul style="list-style-type: none"> Maintains heat pump condenser at design flow rate value. P-2 speed modulates for head pressure control when cooling with cold ground return temperature 	Sensor in HP-1
P-3	Maintains heat pump evaporator at design flow rate value	N/A (fixed speed)
P-4	Off	N/A
P-5	Modulates to maintain the cooling loop differential pressure	DP-4
V-1	Bypass closed (open from ground loop to V-2)	N/A
V-2	Open to the heat pump condenser loop	N/A

Heating-Only Mode

In heating-only mode, the geothermal heat pump operates to control the heating loop supply temperature (Table 27). The cooling loop is off, and the system does not need to control the cooling loop supply temperature. The ground loop is connected to the heat pump evaporator (Figure 63). Ground loop temperature “floats” based on temperature in the ground heat exchanger. This improves compressor efficiency compared to simultaneous heating and cooling mode due to reduced compressor lift. The ground loop flow rate may be controlled to an optimal temperature differential value (refer to section “Ground Loop Pump Energy,” p. 31, for more information).

Figure 63. Blended loop central geothermal system in heating-only mode

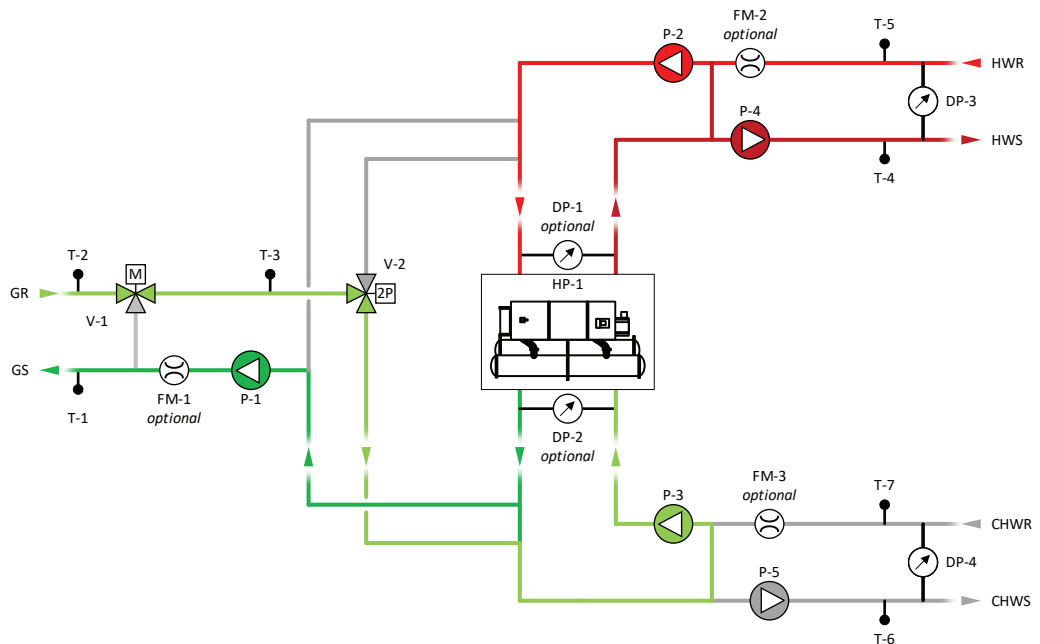


Table 27. Control logic for blended loop central geothermal system in heating-only mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain the leaving condenser temperature at a heating loop supply setpoint	Sensor in HP-1
P-1	Modulates to maintain ground loop temperature at an optimal delta T setpoint	T-1, T-2
P-2	Maintains heat pump condenser at design flow rate value	N/A (fixed speed)
P-3	Maintains heat pump evaporator at design flow rate value	N/A (fixed speed)
P-4	Modulates to maintain the heating loop differential pressure	DP-3
P-5	Off	N/A
V-1	Bypass closed (open from ground loop to V-2)	N/A
V-2	Open to the heat pump evaporator loop	N/A

Simultaneous Mode (Cooling Dominant)

In simultaneous heating and cooling mode, when the system is cooling dominant, the geothermal heat pump operates to control the cooling loop supply temperature (Table 28). The heating loop supply temperature is controlled by modulating the flow in the ground loop (Figure 64). Two stages of ground loop flow modulation are included: stage 1 uses pump speed modulation, and stage 2 uses a bypass valve to divert flow from going through the ground heat exchanger.

Figure 64. Blended loop central geothermal system in cooling dominant mode

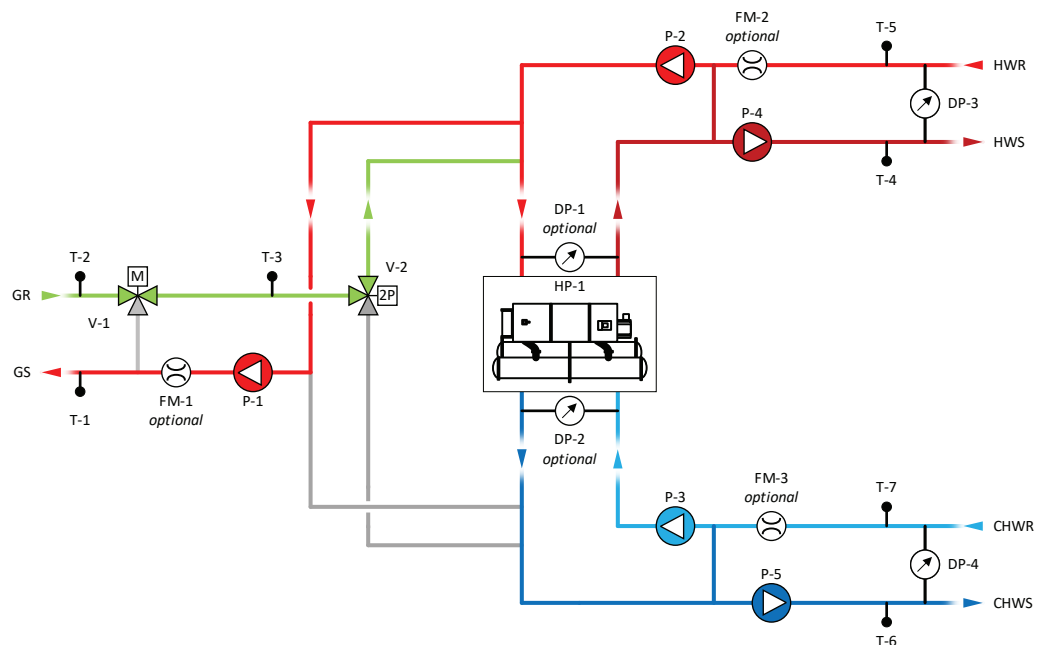


Table 28. Control logic for blended loop central geothermal system in cooling dominant mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain the leaving evaporator temperature to a cooling loop supply setpoint	Sensor in HP-1
P-1	<ul style="list-style-type: none"> Modulates to maintain heating loop supply temperature at the heating setpoint If P-1 has modulated down to minimum speed, V-1 is used for additional modulation 	T-4
P-2	Maintains heat pump condenser at design flow rate value	N/A (fixed speed)
P-3	Maintains heat pump evaporator at design flow rate value	N/A (fixed speed)
P-4	Modulates to maintain the heating loop differential pressure.	DP-3
P-5	Modulates to maintain the cooling loop differential pressure.	DP-4
V-1	If P-1 is at minimum speed, V-1 provides second stage of modulation to maintain heating loop supply temperature at the heating setpoint	T-4, Min speed status of P-1
V-2	Open to the heat pump condenser loop	N/A

Simultaneous Mode (Heating Dominant)

In simultaneous heating and cooling mode, when the system is heating dominant, the geothermal heat pump operates to control the heating loop supply temperature (Table 29). The cooling loop supply temperature is controlled by modulating flow in the ground loop. Two stages of ground loop flow modulation are included: stage 1 uses pump speed modulation, and stage 2 uses a bypass valve to divert flow from going through the ground heat exchanger (Figure 65).

Figure 65. Blended loop central geothermal system in heating dominant mode

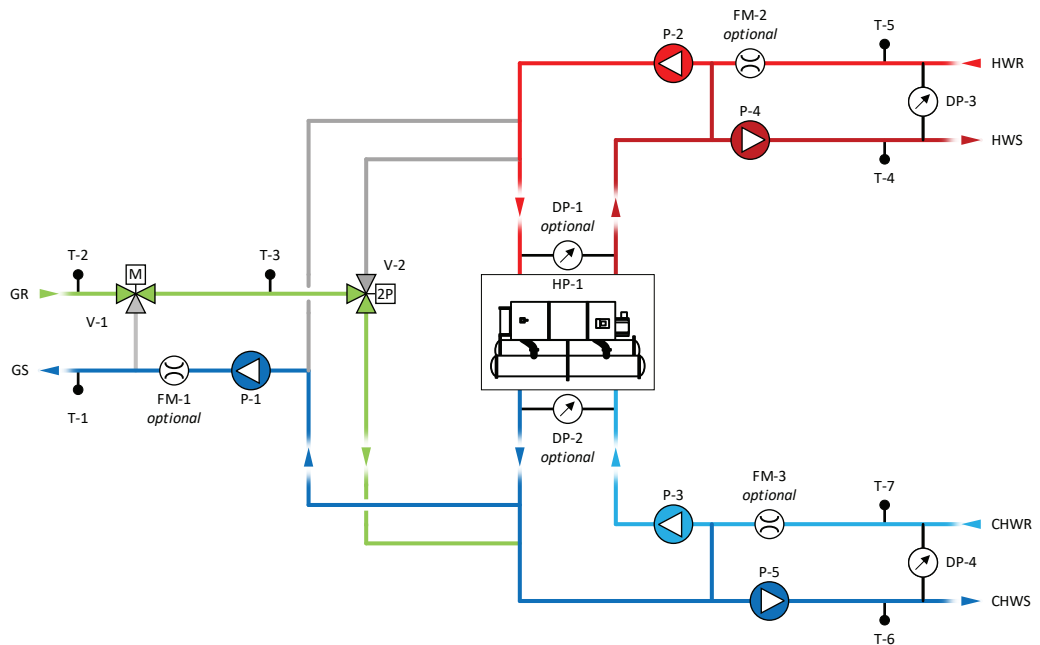


Table 29. Control logic for blended loop central geothermal system in heating dominant mode

Device	Control logic	Linked sensor
HP-1	Modulates to maintain the leaving condenser temperature at a heating loop supply setpoint	Sensor in HP-1
P-1	<ul style="list-style-type: none"> Modulates to maintain cooling loop supply temperature at the cooling setpoint If P-1 has modulated down to minimum speed, V-1 is used for additional modulation 	T-6
P-2	Maintains heat pump condenser at design flow rate value	N/A (fixed speed)
P-3	Maintains heat pump evaporator at design flow rate value	N/A (fixed speed)
P-4	Modulates to maintain the heating loop differential pressure	DP-3
P-5	Modulates to maintain the cooling loop differential pressure	DP-4
V-1	If P-1 is at minimum speed, V-1 provides second stage of modulation to maintain cooling loop supply temperature at the cooling setpoint	T-6, Min speed status of P-1
V-2	Open to the heat pump evaporator loop	N/A

System Options and Alternatives

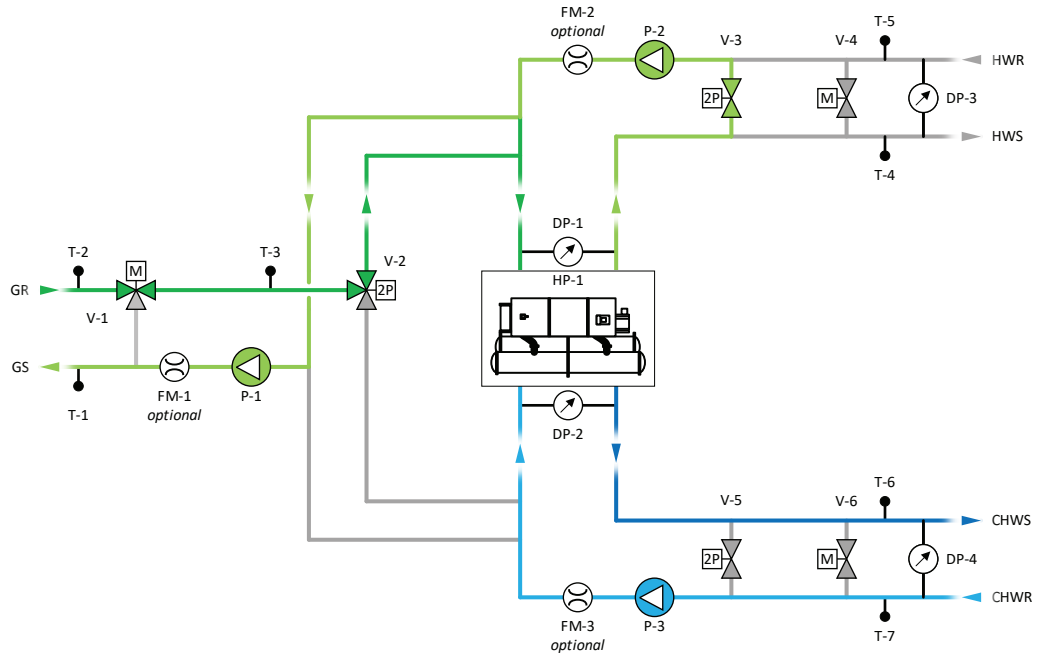
Variable Primary Flow. The base design with decoupled pumping on each loop is intended to simplify the system control. The blended loop central geothermal system may also be designed with variable primary flow on both the heating and cooling loops. Designers should consider the following differences when laying out a blended loop central geothermal system with variable primary flow:

- P-2 and P-3 pump selections must be able to produce the combined head of the distribution system and the heat pumps.
- Differential pressure sensors or flow meters are required on the heat pump evaporator and condenser. These sensors are used for minimum flow control.
- A minimum flow bypass valve must be installed at a remote location in both the heating and cooling loops. The minimum flow bypass is sized for the minimum flow rate of the heat pump chiller.
- Peak cooling capacity requires design flow rate in the condenser loop. This is likely to happen when there is no simultaneous heating load (e.g., cooling-only mode). There are two design options to achieve this:
 - Size the minimum flow bypass for the full design condenser flow rate. Do not sacrifice good control authority at low-flow conditions.
 - Add a heating loop bypass in the equipment room that opens for cooling-only mode. This saves pump energy compared to flowing through the min-flow bypass, which should be installed near the end of the distribution loop. A two-position valve can be used for the full flow bypass.
- Peak heating capacity requires design flow rate in the evaporator loop and is likely to happen when there is no simultaneous cooling load (e.g., heating only mode). Use the same logic as above to size the evaporator loop min-flow bypass or add a cooling loop bypass in the evaporator loop.
- Two methods may be used to control the pump speed and bypass valve position. More information about these methods is included in the "[System Options and Alternatives](#)," p. 58, section for hydronic changeover central geothermal systems.
 - **Method 1:** Primary pump controls heat pump differential pressure; bypass valve controls system differential pressure
 - **Method 2:** Primary pump controls system differential pressure; bypass valve controls heat pump differential pressure.

Blended Loop Central Geothermal System

Figure 66 shows a blended loop central geothermal system with variable primary flow in the heating and cooling loops. Full flow bypasses (V-3 and V-5) are installed in each loop for cooling-only and heating-only modes. Modulating bypass valves (V-4 and V-6) are installed at the end of the distribution loops to ensure minimum flow to the heat pumps. Cooling-only operation is shown.

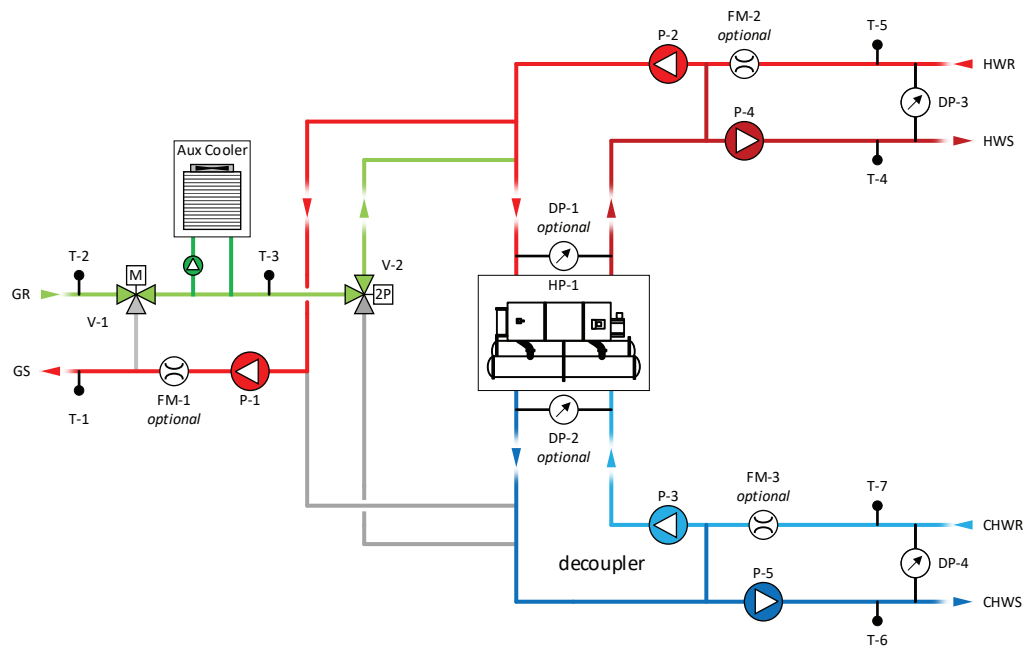
Figure 66. Blended loop central geothermal system with variable primary flow



Auxiliary Coolers

Auxiliary coolers are typically installed on the ground return line (Figure 67). This ensures that the ground heat exchanger receives the warmest fluid and therefore has the opportunity to dissipate heat, even if the ground temperature is warm. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary coolers.

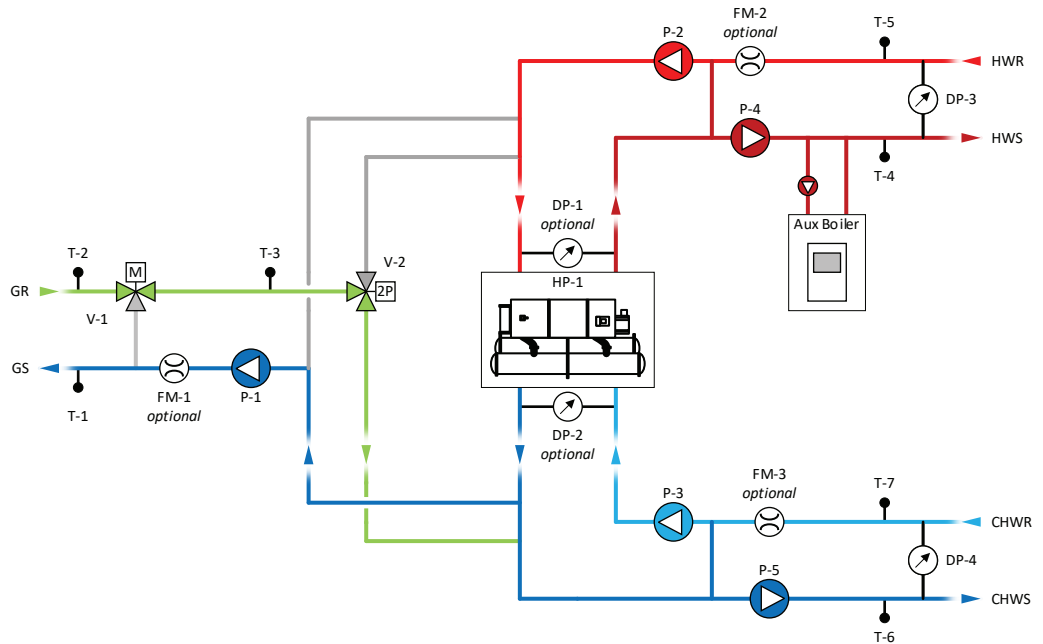
Figure 67. Auxiliary cooler in a blended loop central geothermal system



Auxiliary Boilers

Auxiliary boilers are typically placed in the heating loop, downstream of the heat pumps (Figure 68). This allows the boiler to supplement the heat pump capacity. Refer to section "Geothermal System Design Considerations," p. 10, for more information about auxiliary boilers.

Figure 68. Auxiliary boiler in a blended loop central geothermal system



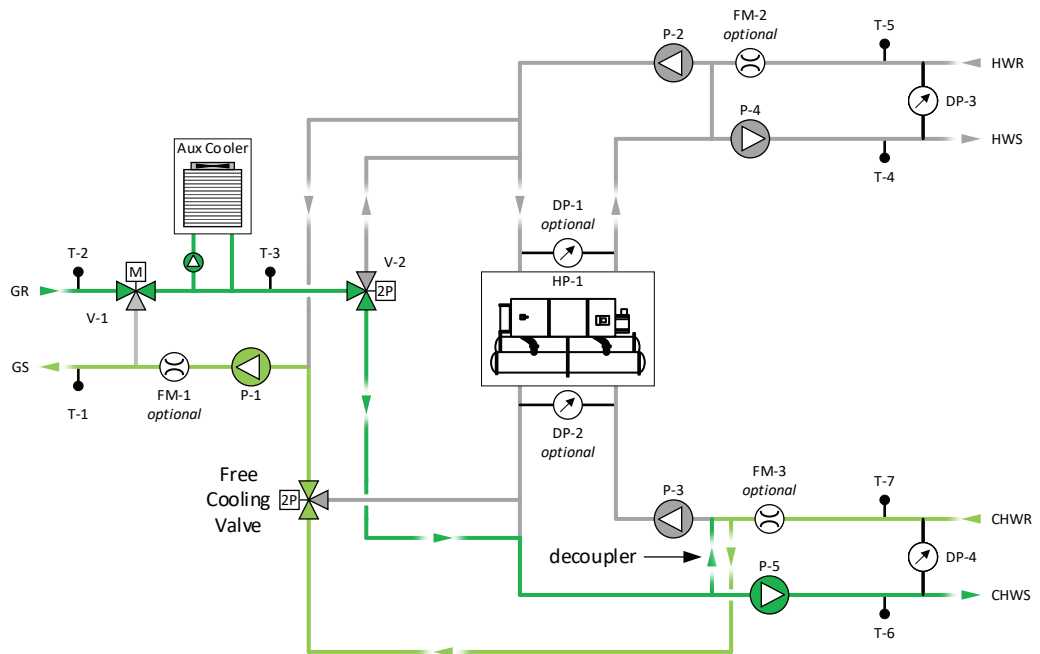
Ground Loop Free Cooling

When the ground loop return temperature is low enough to satisfy the cooling setpoint, the system may operate in ground loop free cooling mode.

The ground loop free cooling method shown in Figure 69 utilizes an additional 3-way valve to simplify pumping in free cooling mode. With this valve in the free cooling position, pumps P-1 and P-5 operate in a decoupled primary-secondary configuration. The flow rate in the ground loop should be greater than the flow rate in the cooling distribution loop. This maintains surplus flow in the decoupler pipe, ensuring that the cooling loop supply temperature equals the ground loop return temperature.

An auxiliary cooler may be used to extend the number of operating hours in free cooling mode.

Figure 69. Blended loop central geothermal system in ground loop free cooling mode



Scaling to Higher Capacity

The capacity of the blended loop central geothermal system may be increased by using two packaged heat pumps (Figure 70). Since the system is designed for simple control and operation, the higher capacity two heat pump alternative is selected to maintain simplicity.

Series counterflow has the following advantages when scaling the blended loop central geothermal system:

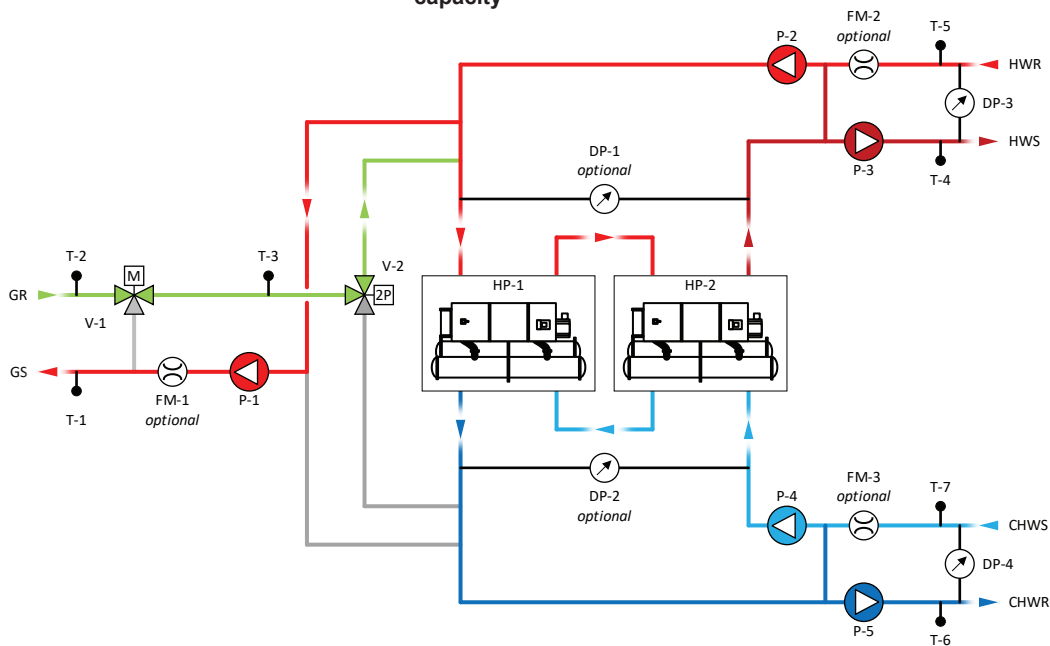
- No additional valve or pump control needs to be added to the base design.
- Sequences of operation are maintained from the base design. The only difference is the setpoint coordination for series-counterflow heat pumps.
- No additional add or subtract sequence is needed for the heat pumps. Proper selection of setpoint temperatures results in the heat pumps naturally staging on and off to maintain the required setpoint temperature.

In a series counterflow design, the downstream unit regulates the system supply temperature. The upstream unit regulates a temperature halfway between the system supply and return temperature. When the system operates below half capacity, the system delta T is lower, and the upstream unit may turn off because it's leaving setpoint temperature is met. The table below (Table 30) provides example setpoints for a blended loop central geothermal system with a series counterflow pair of heat pumps.

Table 30. Example heat pump setpoints for series counterflow operation

Design cooling loop supply	Design cooling loop return	HP-1 cooling setpoint	HP-2 cooling setpoint
42°F (6°C)	56°F (13°C)	42°F (6°C)	49°F (9°C)
Design heating loop supply	Design heating loop return	HP-1 heating setpoint	HP-2 heating setpoint
120°F (49°C)	105°F (41°C)	112°F (44°C)	120°F (49°C)

Figure 70. Blended loop central geothermal system with two heat pumps for higher capacity

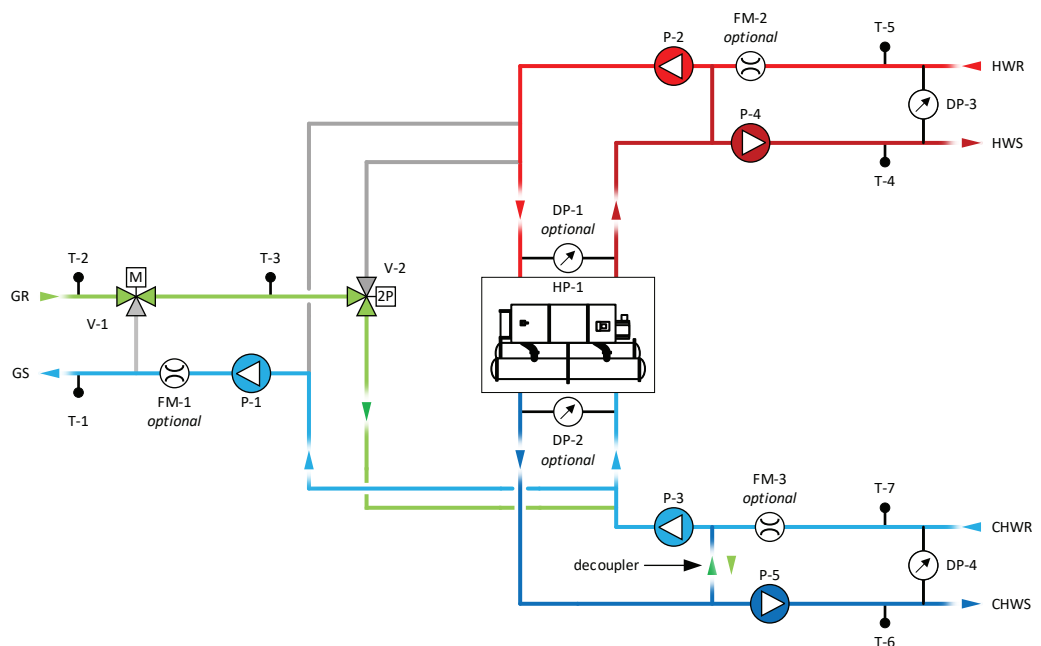


Optimizing for Borefield Operating Temperature Range

All geothermal systems must be designed so the heat pump operating temperatures are high enough to reject heat in cooling mode and low enough to source heat in heating mode. The ground loop connection point in the system has a direct impact on the system's operating temperature limits.

The baseline configuration of the blended loop central geothermal system connects the ground loop to the heat pump evaporator leaving pipe (Figure 71). This allows the system to operate with the ground supply temperature equal to the evaporator leaving temperature. For systems that are expected to have a warmer ground loop temperature, the connection may instead be made to the cooling loop return pipe (evaporator entering pipe). This allows the heat pump to operate at more efficient conditions with less compressor lift. The tradeoff is a smaller range of acceptable ground temperature.

Figure 71. Blended loop central geothermal for warmer ground loop temperature

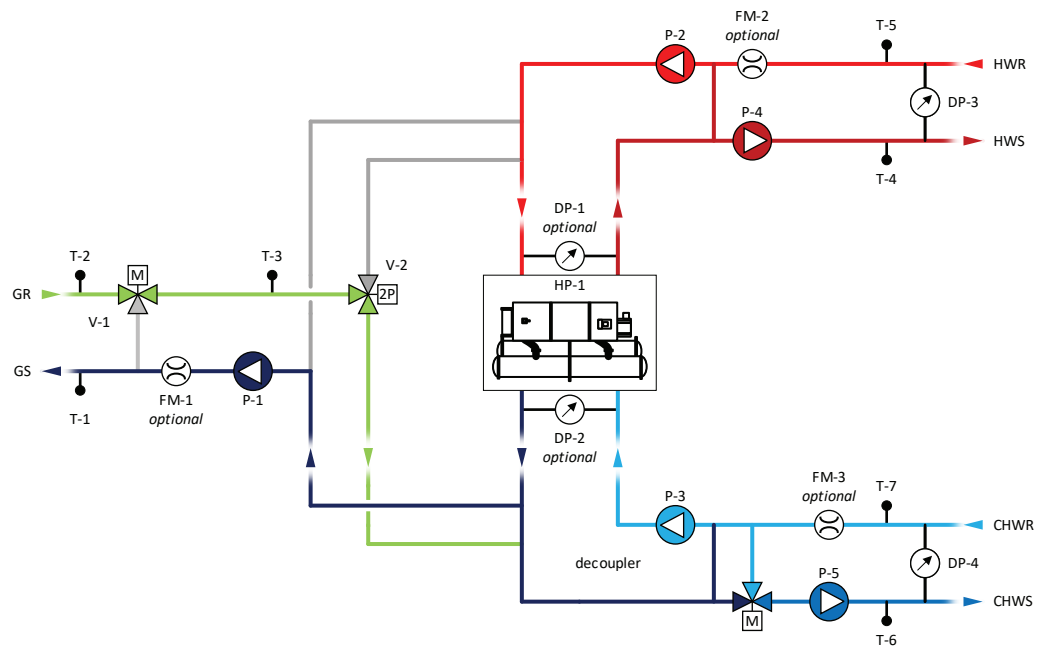


Blended Loop Central Geothermal System

For systems that operate with colder ground temperatures, the heat pump's leaving evaporator temperature must be allowed to drop below the cooling loop setpoint value (Figure 72). In some cases, the fluid temperature after ground loop heat is added may still be below the cooling loop supply setpoint. Two methods to address this problem include:

- Distribute colder fluid to the cooling loads. The terminal devices will throttle flow rate as needed to maintain cooling capacity.
- Adding a blending valve to the cooling loop that recirculates some of the warmer cooling loop return fluid to maintain cooling loop supply temperature.

Figure 72. More extended borefield operating temperatures in a blended loop central geothermal system



Parallel Central Geothermal System

The parallel central geothermal system is designed to provide simultaneous heating and cooling, with the flexibility to operate in heating-only or cooling-only modes. Compared to the blended loop central geothermal system, this system offers higher capacity and improved efficiency, making it ideal for medium to large capacity geothermal systems.

System Requirements and Design Considerations

This system utilizes a bank of heat pump chillers and dedicated control valves that allow each heat pump to operate in heating mode, cooling mode, or simultaneous heating and cooling mode, as required by the building's thermal loads ([Figure 73, p. 90](#)).

The base configuration of the parallel central geothermal system has the following attributes ([Table 31, p. 91](#)):

- Ground loop mode switching is achieved with two 2-way valves, rather than a single 3-way valve. This approach permits the use of larger valves that accommodate higher capacity systems, addressing practical limitations in sourcing cost-effective, large 3-way valves.
- Heat pump operating mode is selected using 2-way "boundary valves". This arrangement requires that heating-only and cooling-only capacity be added from left to right in the flow diagram and simultaneous heating/cooling capacity (e.g., heat recovery capacity) be added from right to left. Refer to section "[System Options and Alternatives](#)," [p. 100](#), for more information about alternative switching and rotation methods for heat pumps.
 - Boundary valve staging logic must ensure that all parts of the hydronic system are connected to an expansion tank. Improper valve staging may result in mechanical damage to piping or valves.
- Ground loop pump energy optimization is achieved by modulating ground loop flow rate to achieve an optimal delta T value. Refer to section "[Ground Loop Pump Energy](#)," [p. 31](#), for more details. Ground loop flow modulation is limited to maintain minimum flow rate in operating heat pumps, based on differential pressure sensor measurements.
- The base configuration uses decouple primary-secondary pumping for both the heating loop and cooling loop. This makes the system simpler to control compared to using variable primary flow. Refer to section "[System Options and Alternatives](#)," [p. 100](#), for more information about variable primary flow alternatives.
- 2-way isolation valves are included for each heat pump, allowing manifolded primary pumps. Modulating control valves may be used instead of 2-way valves to allow active flow balancing or head pressure control (instead of using the ground loop bypass valve). Refer to the section titled "[System Options and Alternatives](#)," [p. 100](#), for more information.
- Head pressure control is managed by a ground loop bypass valve. This may be required for systems operating in cooling-only or cooling dominant modes with low ground return temperature.

In addition to the base configurations, Refer to section "[System Options and Alternatives](#)," p. 100, for more information about the following system alternatives:

- Temperature regulation
- Variable primary flow
- Auxiliary coolers
- Auxiliary boilers
- Ground loop free cooling
- Scaling to lower capacity
- Scaling to higher capacity
- Heat pump staging and rotation
- Independent staging
- Cascading for higher-temperature heating

Component Descriptions

Figure 73. Parallel central geothermal system

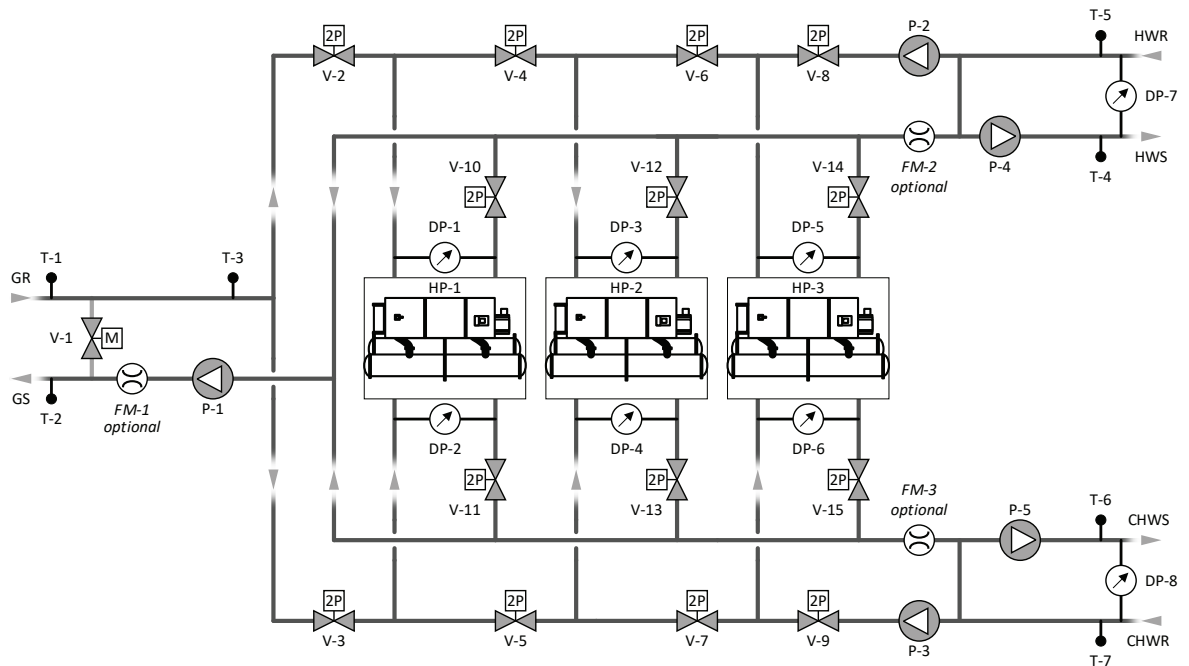


Table 31. Components list for parallel central geothermal system

Component	Description
HP-1, HP-2, HP-3	<p>Geothermal heat pumps:</p> <ul style="list-style-type: none"> • Geothermal heat pumps are water-to-water heat pumps with a non-reversible refrigeration cycle. • They are capable of regulating either heating fluid temperature or cooling fluid temperature. • They operate in heating mode, cooling mode, or simultaneous heating and cooling mode, depending on position of valves in the system.
P-1	<p>Ground loop pump:</p> <ul style="list-style-type: none"> • Ground loop pumps provide flow through the ground heat exchanger and the heat pump evaporators or condensers, depending on the operating mode. • In cooling mode, the heat pump condensers are connected to the ground loop. • In heating mode, the heat pump evaporators are connected to the ground loop. <p>The quantity of heat pumps connected to the ground loop depends on the position of the boundary valves (V-4 through V-7) and the heat pump isolation valves (V-10 through V-15).</p>
P-2	<p>Condenser loop primary pump:</p> <p>The condenser loop primary pump controls the condenser flow rate for heat pumps operating in heating mode or simultaneous heating and cooling mode.</p>
P-3	<p>Evaporator loop primary pump:</p> <p>The evaporator loop primary pump controls the evaporator flow rate for heat pumps operating in cooling mode or simultaneous heating and cooling mode.</p>
P-4	<p>Heating loop distribution pump:</p> <p>The heating loop distribution pump provides distribution flow to the heating loop by maintaining the supply pressure at a remote location.</p>
P-5	<p>Cooling loop distribution pump:</p> <p>The cooling loop distribution pump provides distribution flow to the cooling loop by maintaining the supply pressure at a remote location.</p>
V-1	<p>Ground loop bypass:</p> <ul style="list-style-type: none"> • The ground loop bypass is a modulating control valve that provides head pressure control when cooling with low ground temperature. • Modulating valves at each condenser (V10, V-12, V-14) may be used for head pressure control instead of V-1.
V-2, V-3	<p>Ground loop mode control valves:</p> <p>Ground loop mode control valves V-2 and V-3 are two position valves that direct ground loop flow to either the heat pump condensers or the evaporators, depending on the system operating mode.</p> <ul style="list-style-type: none"> • Ground flow is directed to the condensers for cooling-only or cooling dominant modes. • Ground flow is directed to the evaporators for heating-only or heating dominant modes.
V-4, V-5, V-6, V-7, V-8, V-9	<p>Boundary Valves:</p> <p>The boundary valves are two-position valves that determine the operating mode of each heat pump by connecting the evaporators and condensers to the ground loop, heating loop, or cooling loop.</p> <ul style="list-style-type: none"> • Condenser boundary valves V-4, V-6, and V-8 determine whether the heat pump condensers are connected to the ground loop or the heating loop. • Evaporator boundary valves V-5, V-7, and V-9 determine whether the heat pump evaporators are connected to the ground loop or the cooling loop. <p>Boundary valve staging logic must ensure that all parts of the hydronic system are connected to an expansion tank. Improper valve staging may result in mechanical damage to piping or valves.</p>
V-10, V-11, V-12, V-13, V-14, V-15	<p>Heat pump isolation valves:</p> <ul style="list-style-type: none"> • Heat pump flow control valves are two-position isolation valves that isolate flow to disabled heat pumps. These valves must open and close slowly enough to avoid flow disruptions (e.g., pump speed control must have sufficient time to react to valve operation) • Heat pump isolation valves may be converted to modulating valves and used for active flow balancing or head pressure control (instead of V-1).
T-1, T-2, T-3	<p>Ground loop temperature sensors:</p> <ul style="list-style-type: none"> • Ground loop temperature sensors T-1 and T-2 measure the fluid temperature entering and leaving the ground heat exchanger. These temperatures may be used for ground loop flow optimization. • Optional temperature sensor T-3 is added when head pressure control valve V-1 is used in the system.
T-4, T-5, T-6, T-7	<p>Distribution loop temperature sensors:</p> <ul style="list-style-type: none"> • Distribution loop temperature sensors T-4 and T-5 monitor the heating loop operating temperatures. • Sensors T-6 and T-7 monitor the cooling loop operating temperatures.
DP-1, DP-2, DP-3, DP-4, DP-5, DP-6	<p>Heat pump differential pressure sensors:</p> <p>Pressure sensors DP-1 through DP-6 measure the differential pressure across the heat pump evaporators and condensers. The differential pressure measurement is used for pump flow control.</p>
DP-7, DP-8	<p>Distribution differential pressure sensors:</p> <p>Pressure sensors DP-7 and DP-8 measure the distribution supply pressure at a remote location in the system. Distribution DP measurement is used for distribution pump control.</p>
FM-1, FM-2, FM-3 (optional)	<p>Ground loop and distribution loop flow meters:</p> <ul style="list-style-type: none"> • Flow meters FM-1, FM-2, and FM-3 may be added to improve system reliability by detecting a mismatch between the expected flow (based on differential pressure) and the measured flow. A mismatch may indicate system fouling or clogged strainers. • Flow meters FM-1, FM-2, and FM-3 may also be used for monitoring and Btu calculation.

System Operation and Control

The parallel central geothermal system responds to a BAS call for heating, cooling, or both. The system's heating and cooling capacity is achieved by staging heat pumps to match the load demand. When heating and cooling loads exist simultaneously, the system prioritizes the addition of simultaneous heating and cooling capacity (i.e., heat recovery). Additional heat pumps are then added in heating-only or cooling-only mode, until the load demand is met. [Table 32](#) summarizes the control strategy for the parallel central geothermal system.

Table 32. Heat pump coordination strategy for the parallel central geothermal system

	Cooling loop temperature control	Heating loop temperature control	Ground loop temperature control
Cooling-only mode	Any heat pump may be enabled in cooling mode	Off.	
Heating-only mode	Off	Any heat pump may be enabled in heating mode	
Simultaneous heating and cooling mode - cooling dominant	Stage 2: Cooling-only capacity is added from left to right and set to cooling control mode	Stage 1: Simultaneous heating and cooling capacity is added from right to left and set to heating control mode	Uncontrolled, follows ground temperature
Simultaneous heating and cooling mode - heating dominant	Stage 1: Simultaneous heating and cooling capacity is added from right to left and set to cooling control mode	Stage 2: Heating-only capacity is added from left to right and set to heating control mode	

When the system operates in simultaneous heating and cooling, the BAS must determine whether the system is heating dominant or cooling dominant. The following strategies may be used:

- Outdoor air temperature (OAT) may be used for many buildings. The threshold is set for the balance point temperature of the building (the OAT that results in equal heating and cooling loads). When OAT is below the threshold, the system is assumed to be heating dominant and when OAT is above the threshold, the system is assumed to be cooling dominant.
- Btu meters provide a more precise, real-time measurement of load demand in the heating loop and cooling loops. Flow meters and temperature sensors may also be used to calculate Btu.

Note: Heat pump condenser capacity is greater than the evaporator capacity due to the heat of compression. The shift between heating dominant and cooling dominant conditions happens when the evaporator and condenser capacities are balanced, not when the heating and cooling loads are equal. Balance is typically achieved when condenser capacity is approximately 1.3 times the evaporator capacity. The exact ratio between evaporator and condenser capacity may be calculated from the heat pump performance data.

Cooling-Only Mode

In cooling-only mode, the geothermal heat pumps operate to control cooling loop supply temperature (Figure 74). Heat pumps are added and subtracted as needed to maintain cooling loop supply temperature. The heating loop is off, and the system does not need to control the heating loop supply temperature. The ground loop is connected to the heat pump condenser. Ground loop temperature “floats” based on the temperature in the ground heat exchanger. The ground loop flow rate is controlled to the heat pump condenser’s design flow value. See Table 33 for more details.

Figure 74. Parallel central geothermal system in cooling-only mode

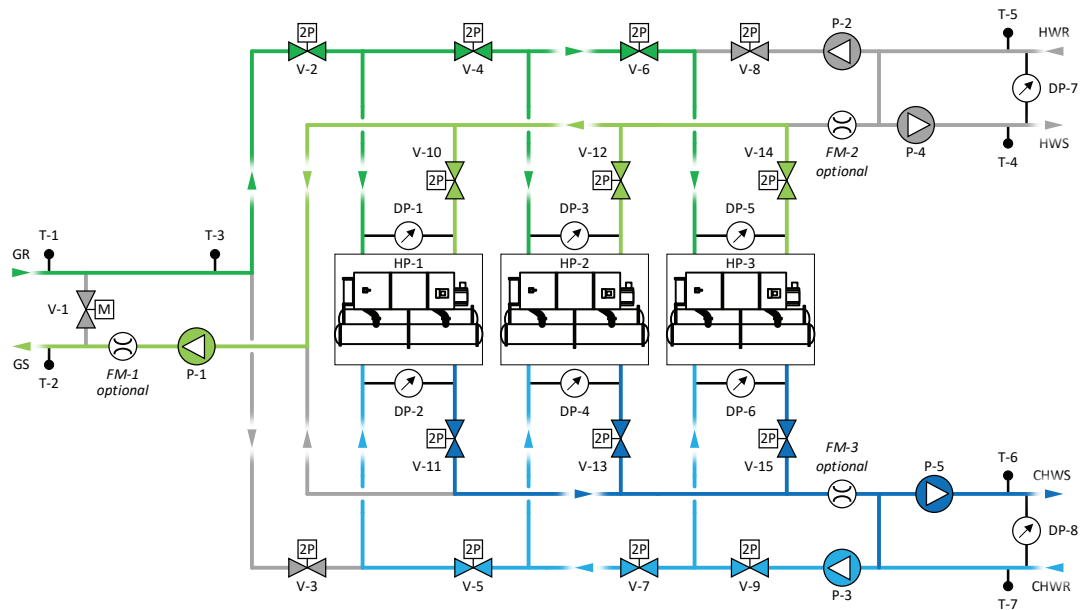


Table 33. Control logic for parallel central geothermal system in cooling-only mode

Device	Control logic	Linked sensor
HP-1, HP-2, HP-3	<ul style="list-style-type: none"> Modulates to maintain leaving evaporator temperature at a cooling loop setpoint BAS adds and subtracts heat pumps as needed to match cooling load demand 	Sensors in HP-1, HP-2, HP-3
P-1	Modulates to maintain optimal ground loop differential temperature, with a minimum flow based on differential pressure at the condensers of operating heat pumps	T-1, T-3 DP-1, DP-3, DP-5
P-2	Off	N/A
P-3	Modulates to maintain design differential pressure at the evaporators of operating heat pumps	DP-2, DP-4, DP-6
P-4	Off	N/A
P-5	Modulates to maintain the cooling loop differential pressure	DP-8
V-1	<ul style="list-style-type: none"> Modulates to maintain minimum head pressure for HP-1 Check with the heat pump manufacturer for minimum head pressure requirements Modulating valves at V-10, V-12, and V-14 may also be used for head pressure control 	Sensor in HP-1, HP-2, and HP-3 or T-3 and T-6
Ground loop mode: V-2, V-3	<ul style="list-style-type: none"> V-2 is open, connecting the ground loop to the heat pump condenser loop V-3 is closed, isolating the ground loop from the heat pump evaporator loop 	N/A
Boundary valves: V-4, V-5, V-6, V-7, V-8, V-9	<ul style="list-style-type: none"> V-4 and V-6 are open, connecting the ground loop to all heat pump condensers V-5, V-7, and V-9 are open, connecting the cooling loop to all heat pump evaporators V-8 is closed, isolating the ground loop from the heating loop 	N/A
Isolation valves: V-10, V-11, V-12, V-13, V-14, V-15	Heat pump isolation valves open when the associated heat pump is enabled and close after it is disabled	N/A

Heating-Only Mode

In heating-only mode, the geothermal heat pumps operate to control the heating loop supply temperature (Figure 75). Heat pumps are added and subtracted as needed to maintain the heating loop supply temperature. The cooling loop is off, and the system does not need to control the cooling loop supply temperature. The ground loop is connected to the heat pump evaporator. Ground loop temperature “floats” based on the temperature in the ground heat exchanger. The ground loop flow rate is controlled to the heat pump condenser’s design flow value. See Table 34 for more details.

Figure 75. Parallel central geothermal system in heating-only mode

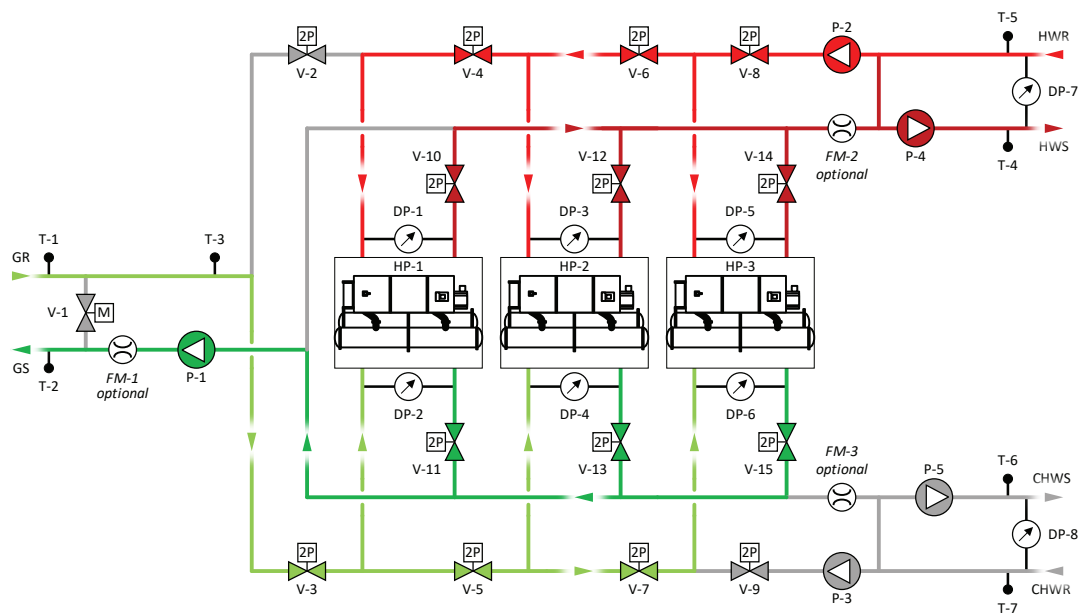


Table 34. Control logic for parallel central geothermal system in heating-only mode

Device	Control logic	Linked sensor
HP-1, HP-2, HP-3	<ul style="list-style-type: none"> Modulates to maintain leaving condenser temperature at a heating loop setpoint BAS adds and subtracts heat pumps as needed to match heating load demand 	Sensors in HP-1, HP-2, HP-3
P-1	Modulates to maintain optimal ground loop differential temperature, with a minimum flow based on differential pressure at the evaporators of operating heat pumps	T-1, T-2 DP-2, DP-4, DP-6
P-2	Modulates to maintain design differential pressure at the condensers of operating heat pumps	DP-1, DP-3, DP-5
P-3	Off	N/A
P-4	Modulates to maintain the heating loop differential pressure	DP-7
P-5	Off	N/A
V-1	Closed <i>Note: V-1 does not require a mode-dependent, forced closure. It will naturally close because head pressure control is not needed.</i>	N/A
Ground loop mode: V-2, V-3	<ul style="list-style-type: none"> V-2 is closed, isolating the ground loop from the heat pump condenser loop V-3 is open, connecting the ground loop to the heat pump evaporator loop 	N/A
Boundary valves: V-4, V-5, V-6, V-7, V-8, V-9	<ul style="list-style-type: none"> V-4, V-6, and V-8 are open, connecting all heat pump condensers to the heating loop V-5, and V-7 are open, connecting the ground loop to all heat pump evaporators V-9 is closed, isolating the ground loop from the cooling loop 	N/A
Isolation valves: V-10, V-11, V-12, V-13, V-14, V-15	Heat pump isolation valves open when the associated heat pump is enabled and close after it is disabled	N/A

Simultaneous Heating and Cooling (Cooling Dominant)

In cooling dominant conditions, the system prioritizes simultaneous heating and cooling capacity first, because it is the most efficient mode of operation. Simultaneous capacity must be added from the right side of the system (Figure 76). Heat pumps operating in simultaneous heating and cooling mode regulate the non-dominant (heating) supply temperature. Additional capacity needed to satisfy the dominant (cooling) supply temperature is added from left to right. See Table 35, p. 97, for more details.

Figure 76. Parallel central geothermal system in cooling dominant mode:

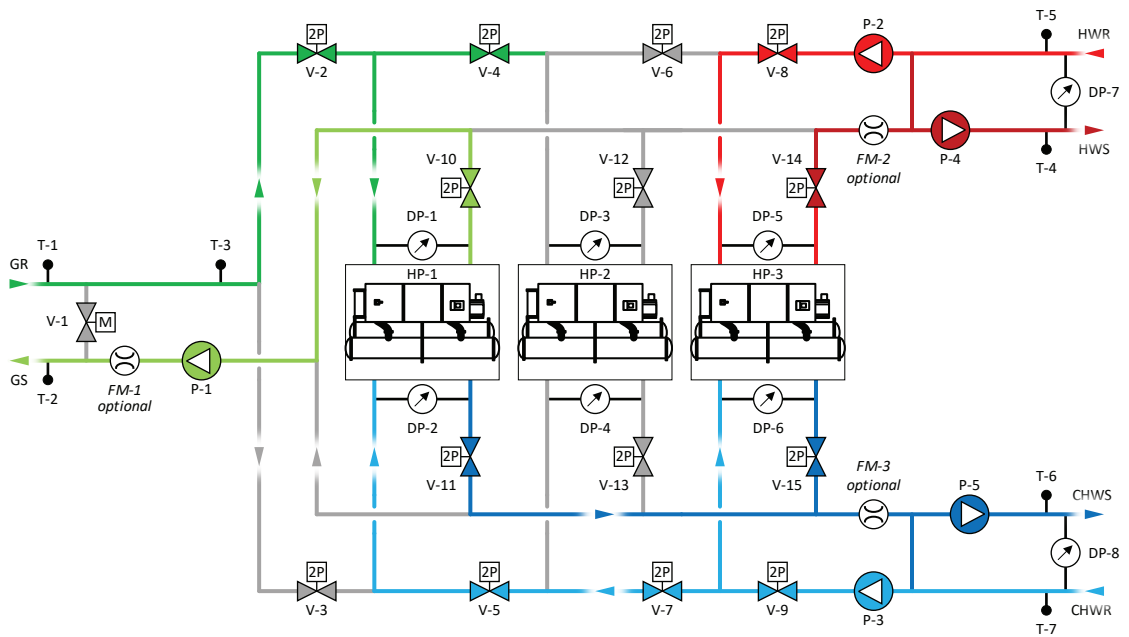


Table 35. Control logic for parallel central geothermal system in cooling dominant mode

Device	Control logic	Linked sensor
HP-1, HP-2, HP-3	<ul style="list-style-type: none"> HP-3 modulates to maintain leaving condenser temperature at heating loop setpoint HP-1 modulates to maintain leaving evaporator temperature. The BAS resets HP-1 setpoint to maintain cooling loop supply T-6, offsetting differences between HP-3 leaving evaporator temperature and the cooling loop supply setpoint HP-2 may operate in simultaneous heating and cooling mode (helping HP-3) or in cooling only mode (helping HP-1), depending on the system load demand 	Sensors in HP-1, HP-2, HP-3
P-1	Modulates to maintain optimal ground loop differential temperature, with a minimum flow based on differential pressure at the condensers of heat pumps operating in cooling only mode	T-1, T-2 DP-1, DP-3 if HP-2 is in cooling mode
P-2	Modulates to maintain design differential pressure at the condensers of heat pumps operating in simultaneous heating and cooling mode	DP-5, DP-3 if HP-2 is in simultaneous mode
P-3	Modulates to maintain design differential pressure at the evaporators of all operating heat pumps	DP-2, DP-4, DP-6
P-4	Modulates to maintain the heating loop differential pressure	DP-7
P-5	Modulates to maintain the cooling loop differential pressure	DP-8
V-1	<ul style="list-style-type: none"> Modulates to maintain minimum head pressure for HP-1 Check with the heat pump manufacturer for minimum head pressure requirements Modulating valves at V-10, V-12, and V-14 may also be used for head pressure control 	Sensor in HP-1, HP-2, and HP-3 or T-3 and T-6
Ground loop mode: V-2, V-3	<ul style="list-style-type: none"> V-2 is open, connecting the ground loop to the heat pump condenser loop V-3 is closed, isolating the ground loop from heat pump evaporator loop 	N/A
Boundary valves: V-4, V-5, V-6, V-7, V-8, V-9	<ul style="list-style-type: none"> V-8 is open, connecting the heating loop to the heat pump condenser loop V-5, V-7, V-9 are open, connecting the cooling loop to all heat pump evaporators V-4 and V-6 position depends on HP-2 operating mode. One valve must be closed to isolate the heating loop from the ground loop while the other is open to ensure that HP-2 condenser is connected to an expansion tank 	N/A
Isolation valves: V-10, V-11, V-12, V-13, V-14, V-15	Heat pump isolation valves open when the associated heat pump is enabled and close after it is disabled	N/A

Simultaneous Heating and Cooling (Heating Dominant)

In heating dominant conditions, the system prioritizes simultaneous heating and cooling capacity first, because it is the most efficient mode of operation (Figure 77). Simultaneous capacity must be added from the right side of the system. Heat pumps operating in simultaneous heating and cooling mode regulate the non-dominant (cooling) supply temperature. Additional capacity needed to satisfy the dominant (heating) supply temperature is added from left to right. See Table 36, p. 99, for more details.

Figure 77. Parallel central geothermal system in heating dominant mode

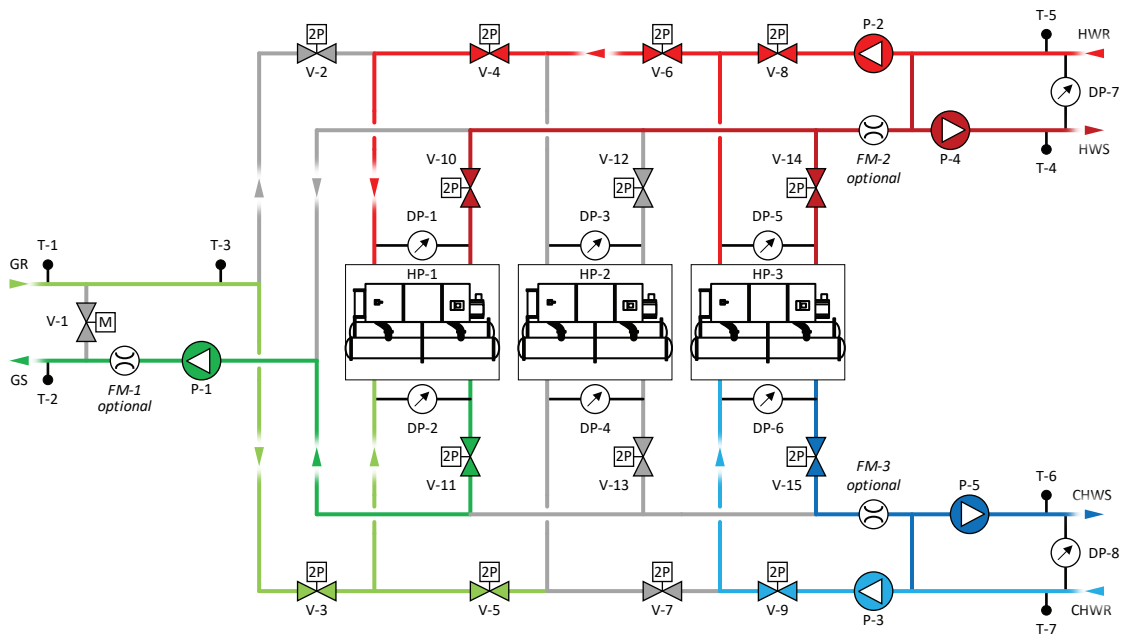


Table 36. Control logic for parallel central geothermal system in heating dominant mode

Device	Control logic	Linked sensor
HP-1, HP-2, HP-3	<ul style="list-style-type: none"> HP-3 modulates to maintain leaving evaporator temperature at cooling loop setpoint HP-1 modulates to maintain leaving condenser temperature. The BAS resets HP-1 setpoint to maintain heating loop supply T-4, offsetting differences between HP-3 leaving condenser temperature and the heating loop supply setpoint HP-2 may operate in simultaneous heating and cooling mode (helping HP-3) or in heating only mode (helping HP-1), depending on the system load demand 	Sensors in HP-1, HP-2, HP-3
P-1	Modulates to maintain optimal ground loop differential temperature, with a minimum flow based on differential pressure at the evaporators of heat pumps operating in heating only mode	T-1, T-2 DP-2, DP-4 if HP-2 is in heating mode
P-2	Modulates to maintain design differential pressure at the condensers of all operating heat pumps	DP-1, DP-3, DP-5
P-3	Modulates to maintain design differential pressure at the evaporators of heat pumps operating in simultaneous heating and cooling mode	DP-6, DP-4 if HP-2 is in simultaneous mode
P-4	Modulates to maintain the heating loop differential pressure	DP-7
P-5	Modulates to maintain the cooling loop differential pressure	DP-8
V-1	Closed <i>Note: V-1 does not require a mode-dependent, forced closure. It will naturally close because head pressure control is not needed.</i>	N/A
Ground loop mode: V-2, V-3	<ul style="list-style-type: none"> V-2 is closed, isolating the ground loop from the heat pump condenser loop V-3 is open, connecting the ground loop to heat pump evaporator loop 	N/A
Boundary valves: V-4, V-5, V-6, V-7, V-8, V-9	<ul style="list-style-type: none"> V-4, V-6, and V-8 are open, connecting the heating loop to the heat pump condenser loop V-9 is open, connecting the cooling loop to the heat pump evaporator loop V-5 and V-7 position, depends on HP-2 operating mode. One valve must be closed to isolate the cooling loop from the ground loop while the other is open to ensure that HP-2 evaporator is connected to an expansion tank 	N/A
Isolation valves: V-10, V-11, V-12, V-13, V-14, V-15	Heat pump isolation valves open when the associated heat pump is enabled and close after it is disabled	N/A

System Options and Alternatives

Temperature Regulation

When simultaneous heating and cooling loads exist, the parallel central geothermal system controller must regulate both the heating loop supply temperature and the cooling loop supply temperature. In simultaneous heating and cooling modes, HP-3 regulates the non-dominant load temperature.

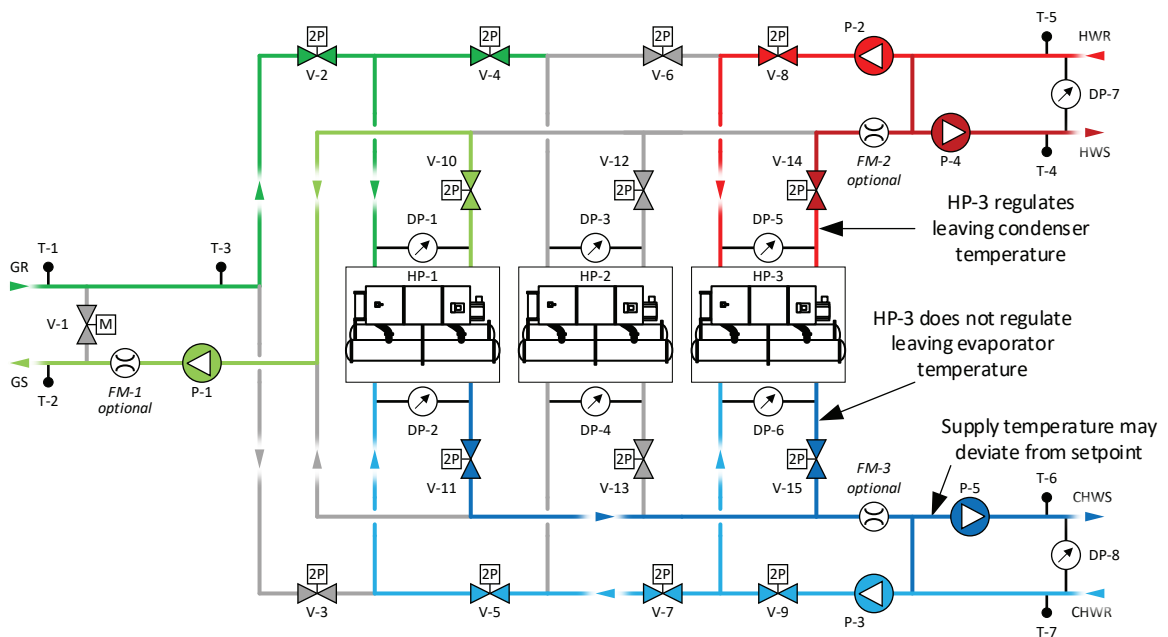
- When the system is cooling dominant, HP-3 regulates the leaving condenser temperature. The leaving evaporator (cooling) temperature is not regulated.
- When the system is heating dominant, HP-3 regulates the leaving evaporator temperature. The leaving condenser (heating) temperature is not regulated.

The supply temperature for the dominant loop is based on the mixing of fluids from all operating heat pumps. If the unregulated fluid from HP-3 deviates from setpoint value, the temperature after mixing may be calculated with the following equation.

$$Temperature_{mixed} = \frac{Temperature_1 * Flow_1 + Temperature_2 * Flow_2}{Flow_1 + Flow_2}$$

The Figure 78 shows a parallel central geothermal system operating in cooling dominant conditions. HP-1 regulates the leaving evaporator temperature, while HP-3 regulates the leaving condenser temperature. The unregulated evaporator fluid from HP-3 mixes with the regulated fluid from HP-1. The cooling loop supply temperature may deviate from the setpoint value.

Figure 78. Temperature regulation in the parallel central geothermal system



Several strategies may be used to improve temperature regulation in parallel central geothermal systems that operate with simultaneous heating and cooling loads. Option 1 is used in the base system operation and control. Designers may also consider other options.

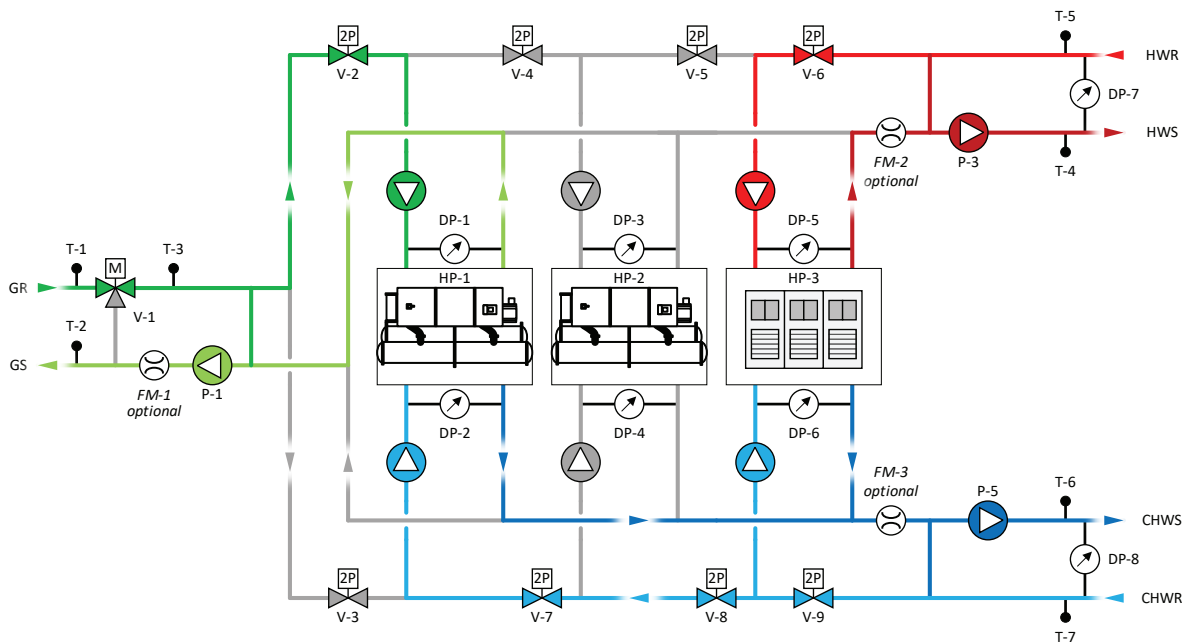
1. **Setpoint reset for HP-1 and HP-2:** The BAS monitor the system supply temperatures with T-4 and T-6. When the system supply temperature deviates from setpoint, the BAS may adjust the setpoints for HP-1 and HP-2 to compensate.
2. **Downsize HP-3:** Simultaneous heating and cooling loads are often small compared to the peak load value. Sizing HP-3 for the simultaneous heating and cooling loads allows it to operate closer to design capacity, where the unregulated temperature is closer to the design value. Downsizing HP-3 also results in a lower flow rate of unregulated fluid, reducing the impact on the system supply temperature.
3. **Modulate flow in HP-3:** Some engineers consider modulating control valves to restrict flow rate on the unregulated side of the HP-3, thereby affecting the delta T value and HP-3 leaving fluid temperature. This strategy, although technically possible, poses the risk of flow control issues—such as excessively restricting the flow of HP-3, causing low-flow cutouts or other heat pump diagnostics. Use caution if attempting this strategy.
4. **Select a modular heat pump for HP-3:** Modular heat pumps include flow isolation valves in each module. At part load conditions, flow is turned off in the non-operating modules, creating a stepped, variable flow characteristic. This achieves the temperature benefits of strategy #3, "Modulate flow in HP-3," with less risk of low-flow diagnostics.

Note: *Manifolded primary pumps deliver the same supply pressure to all connected heat pumps. Combining modular and packaged heat pumps requires careful unit selection. If the heat pump flow and pressure drop characteristics are not matched, dedicated pumps or flow balancing may be required.*

Parallel Central Geothermal System

Figure 79 illustrates a parallel central geothermal system that incorporates two of the temperature regulation strategies listed above: strategy 2 (downsizing HP-3) and strategy 3 (selecting a modular heat pump for HP-3). Dedicated primary pumps are used to avoid flow-differential-pressure mismatches between the packaged heat pumps and the modular heat pumps.

Figure 79. Parallel central geothermal system with smaller capacity modular heat pump for HP-3



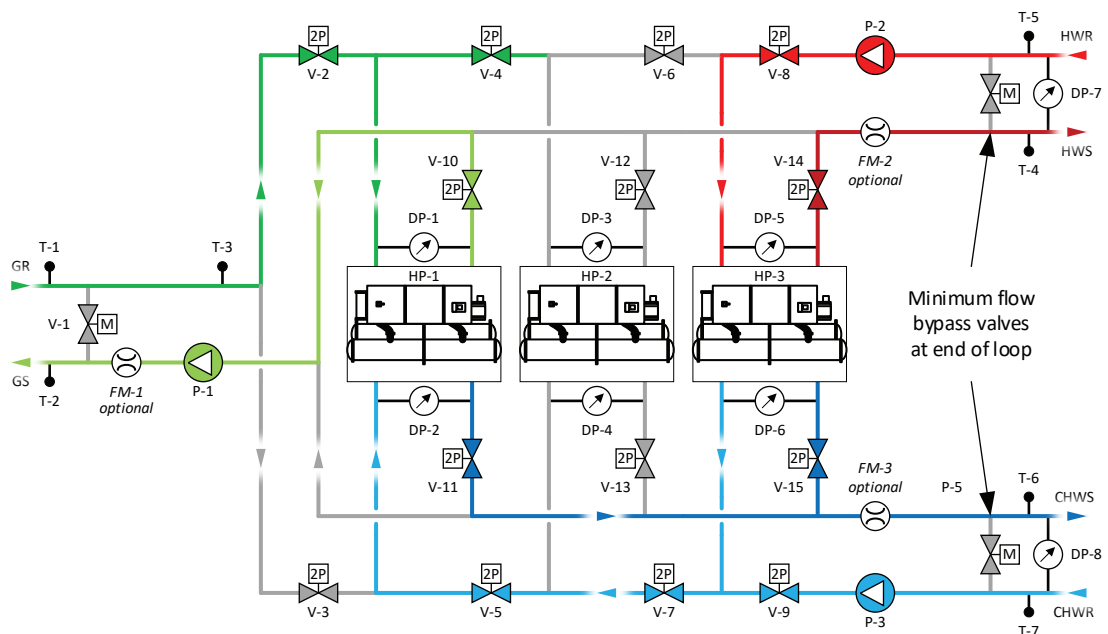
Pump and Flow Control - Variable Primary Flow

The base design with decoupled pumping on each loop is intended to simplify system control. The parallel central geothermal system may also be designed with variable primary flow on both the heating and cooling loops. Designers should consider the following differences when laying out a blended loop central geothermal system with variable primary flow:

- P-2 and P-3 pump selections must be able to produce the combined head of the distribution system and the heat pumps.
- Modulating minimum flow bypass valves must be installed near the end of the heating loop and cooling loop to maintain heat pump minimum flow when system flow is low.
- The ground loop does not require minimum flow bypass since the bores do not have control valves that restrict flow.

The example diagram below (Figure 80) shows a parallel central geothermal system with variable primary flow for both the heating loop and cooling loop.

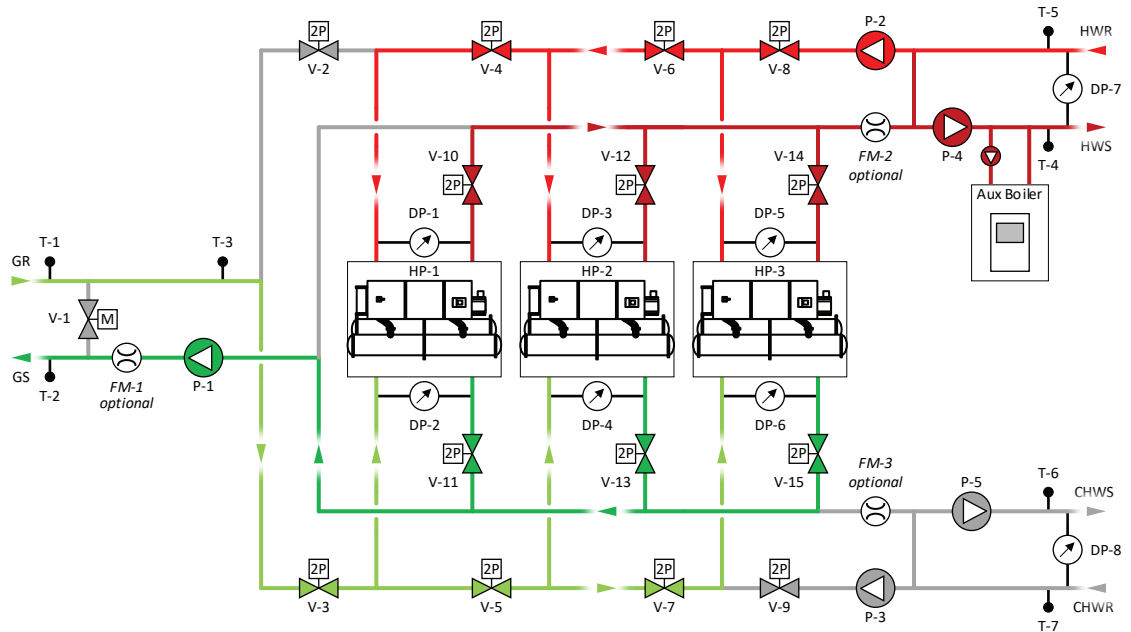
Figure 80. Parallel central geothermal system with variable primary flow



Auxiliary Boilers

Auxiliary boilers are typically placed in the heating loop, downstream of the heat pumps (Figure 82). This allows the boiler to supplement heat pump capacity. Refer to the section "Geothermal System Design Considerations," p. 10, for more information about auxiliary boilers.

Figure 82. Auxiliary boiler in a parallel central geothermal system



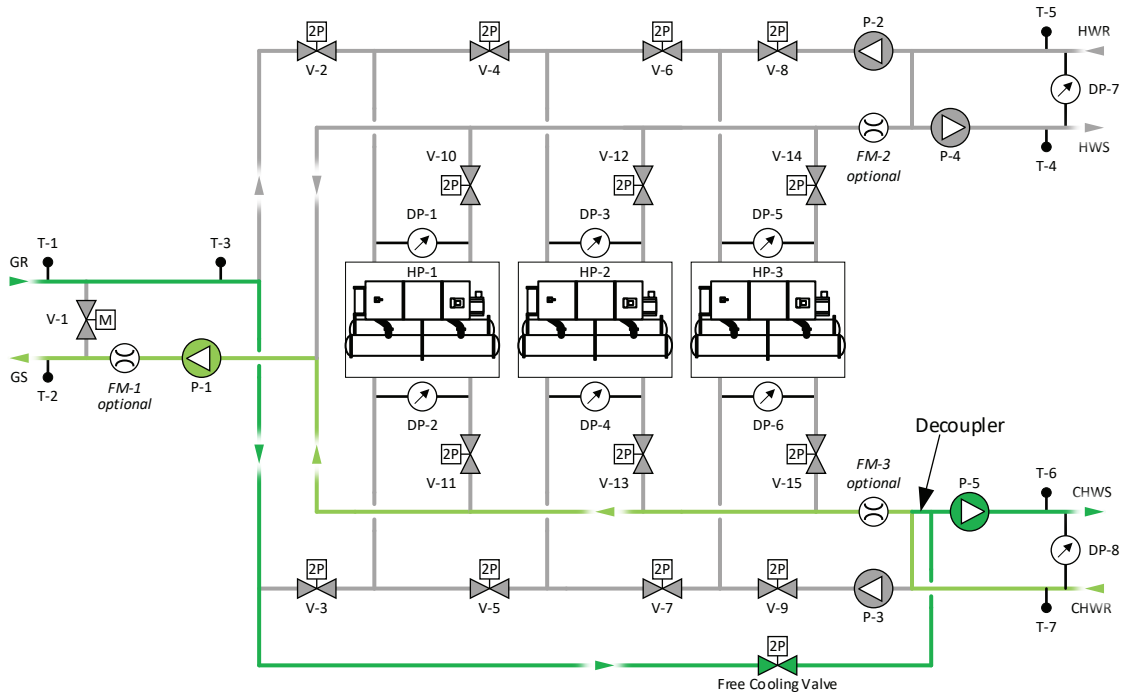
Ground Loop Free Cooling

When the ground return temperature is low enough to satisfy the cooling setpoint, the system may run in ground loop free cooling mode.

The ground loop free cooling method shown below (Figure 83) utilizes an additional 2-way valve to simplify pumping in free cooling mode. With this valve in the free cooling position, pumps P-1 and P-5 operate in a decoupled primary-secondary fashion. The flow rate in the ground loop should be greater than the flow rate in the cooling loop to maintain surplus flow in the decoupler pipe. This prevents the cooling loop return fluid from recirculating back into the supply pipe and degrading the supply temperature.

An auxiliary cooler may be used to extend the number of operating hours in free cooling mode.

Figure 83. Ground loop free cooling in parallel central geothermal systems



Scaling to Lower Capacity

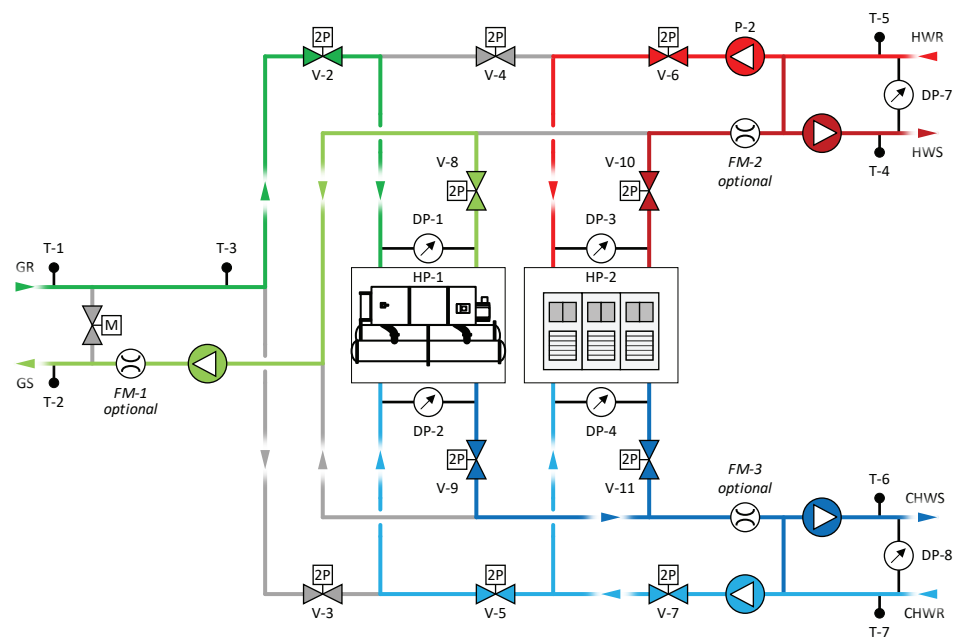
The parallel central geothermal system may be scaled down from three heat pumps to two heat pumps. Designers considering a reduced scale parallel central geothermal system should also consider the series counterflow blended loop system presented in the section "[System Options and Alternatives](#)," p. 81, for blended loop central geothermal systems.

The parallel central geothermal system with two heat pumps may be more efficient than the blended loop system because one of the heat pumps can operate with reduced lift. However, the blended loop central geothermal system is simpler to control, and the temperature regulation may be better than a parallel central geothermal system with two heat pumps.

Designers using a parallel central geothermal system with two heat pumps must pay close attention to temperature regulation, especially when HP-2 operates at light loads. Refer to section "[Temperature Regulation](#)," p. 100, earlier in this chapter.

In the example below ([Figure 84](#)), HP-2 is a modular heat pump sized for the simultaneous heating and cooling load while HP-1 is sized for the peak heating or heat cooling load.

Figure 84. Parallel central geothermal system with two heat pumps



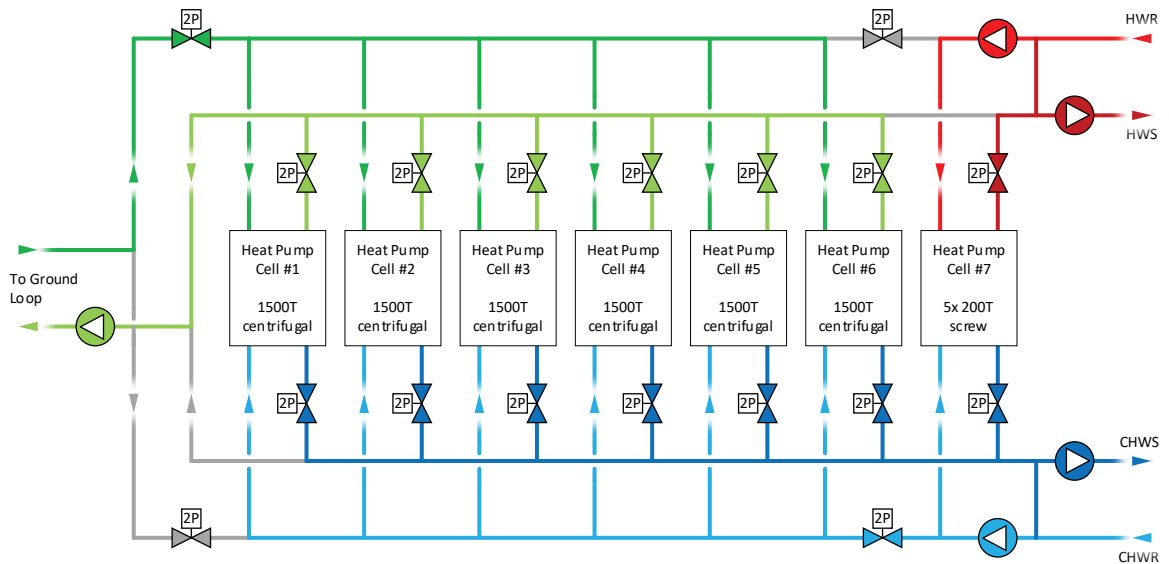
Scaling to Higher Capacity

The parallel central geothermal system can be easily scaled to higher capacity by increasing the number of units operating in parallel. For example, selecting six heat pumps, each with a capacity of 200 tons (703 kW), achieves a parallel central geothermal capacity of 1,200 tons (4,220 kW).

Larger central geothermal plants, such as 2,000 tons (7,034 kW) and above, may consider centrifugal compressor heat pumps for higher capacity. When centrifugal compressor heat pumps are used, designers must evaluate the unloading profile to avoid surge conditions. A combination of centrifugal and screw compressor heat pumps can achieve high capacity with fewer heat pumps, while also having good capacity turndown.

Figure 85 shows a 10,000 ton (35,170 kW) central geothermal plant using six centrifugal compressor heat pumps for high capacity and five screw compressor heat pumps. The screw compressor heat pumps are sized to cover the simultaneous heating and cooling loads, while the centrifugal compressor heat pumps are sized for the peak heating and peak cooling values. This design limits the quantity of boundary valves by changing the mode of all centrifugal compressor heat pumps as a group and all screw compressor heat pumps as another group. Fewer boundaries means fewer boundary valves.

Figure 85. 10,000 tons (35,170 kW) parallel central geothermal system

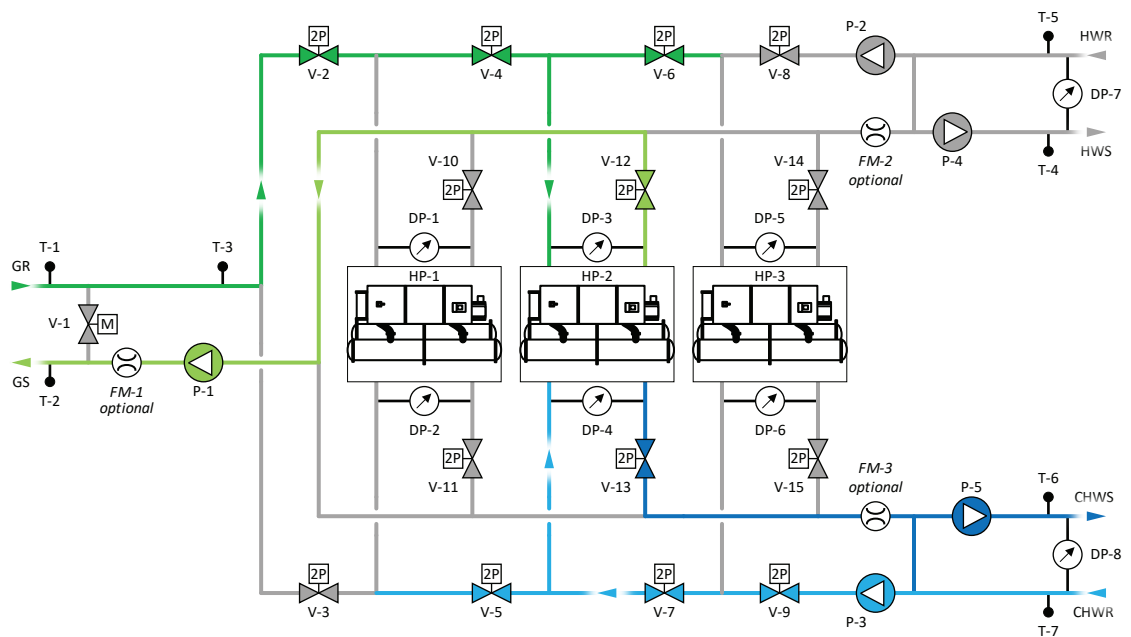


Heat Pump Staging and Rotation

Many central plants include chiller or heat pump rotation strategies to balance equipment run time. The parallel central geothermal system has a limitation in that simultaneous heating and cooling capacity is staged from right to left, while heating-only and cooling-only capacity is staged from left to right. Heat pumps in the middle of the plant may experience fewer run hours. The following strategies may be used to balance heat pump run time in parallel central geothermal systems:

Method 1: Use HP-2 as the lead unit for heating-only and cooling-only conditions (Figure 86). In heating-only and cooling-only modes, the heat pump operating modes are not limited by position in the system.

Figure 86. Parallel central geothermal system with HP-2 operating as lead unit for cooling-only mode



Parallel Central Geothermal System

Method 2: Use HP-2 as a “flex” unit in simultaneous heating and cooling modes (Figure 87). HP-2 may take over run hours from HP-3 by operating in simultaneous heating and cooling mode, or HP-2 may take over run hours from HP-1 by operating in heating-only or cooling-only modes (Figure 88).

Figure 87. Parallel central geothermal system with HP-2 “flexing” to simultaneous mode

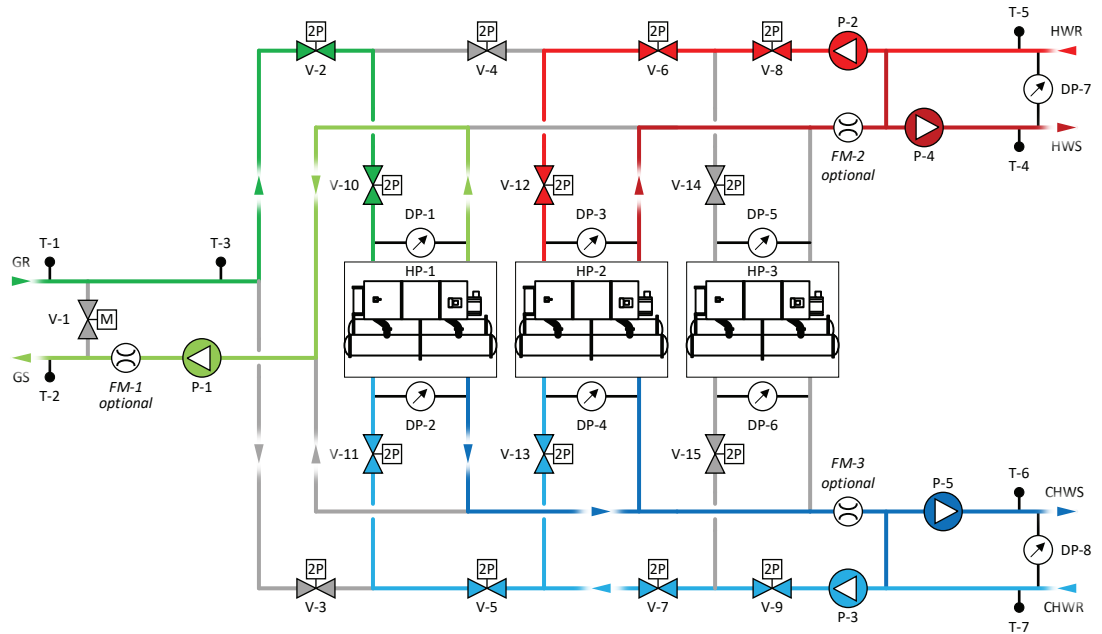
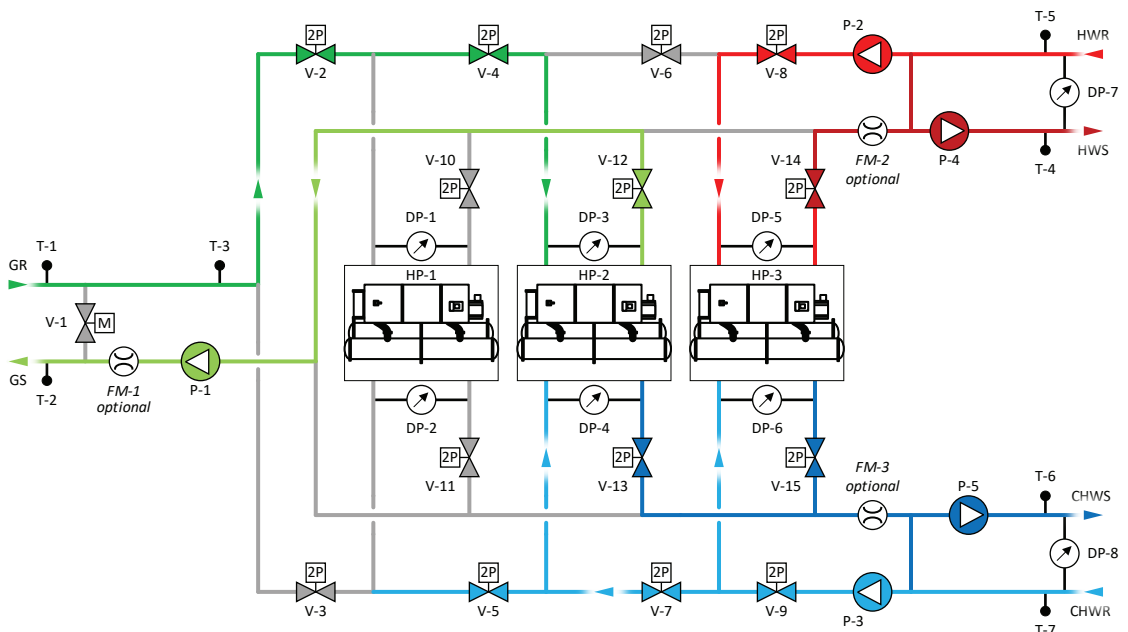


Figure 88. Parallel central geothermal system with HP-2 “flexing” to cooling-only mode

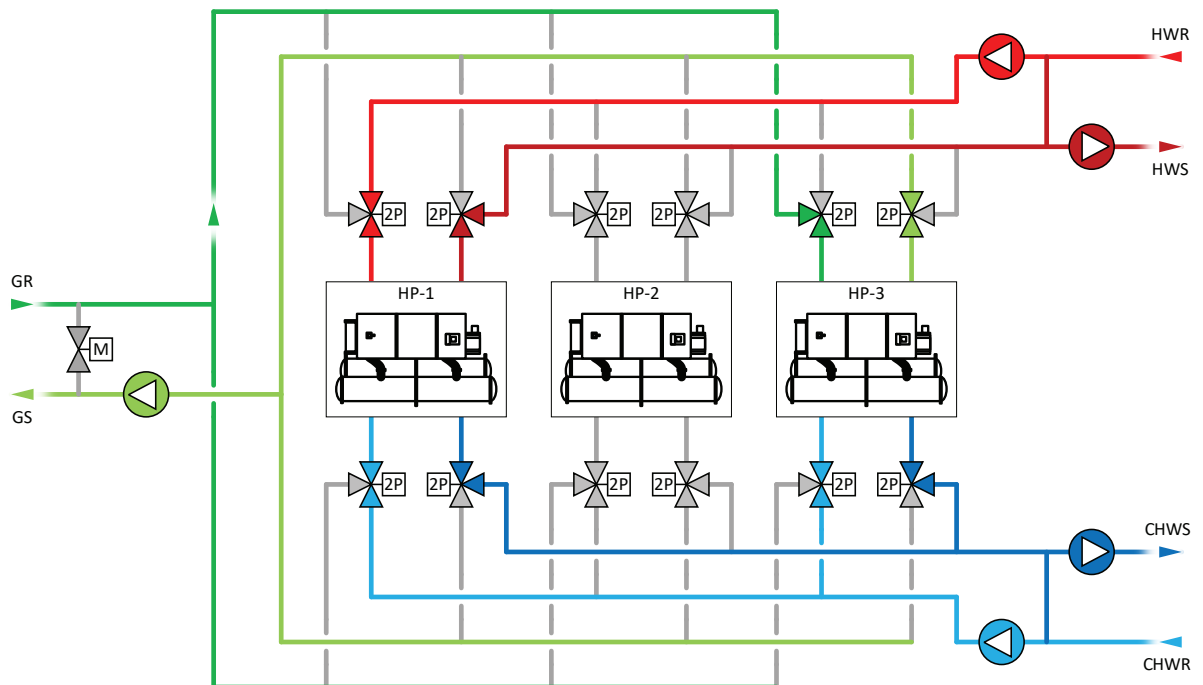


Independent Staging

Some designs may not accept the limitation of heat pump operating mode based on position in the system. Alternate valve arrangements are possible and allow independent mode selection for each heat pump, regardless of its position in the system. The tradeoff is a higher valve count, which translates to higher installed cost.

Figure 89 shows independent staging for a parallel central geothermal system in cooling dominant mode. HP-1 provides simultaneous heating and cooling capacity, while HP-3 provides cooling-only capacity. These assignments are the opposite from the base system description and illustrate the flexibility provided by independent staging.

Figure 89. Parallel central geothermal system with independent staging



Additional examples of booster heat pumps and cascaded heating systems are provided in Trane Application Guide SYS-APG003*, "Air-to-Water Heat Pump System with Cascade Option."

Cascading for Higher-Temperature Heating

Most geothermal systems are designed with high efficiency in mind. The selection of the heating fluid temperature plays a major role in achieving premium system efficiency. High-temperature heating results in high compressor lift, especially when the ground loop return temperature is low.

High heating temperature also affects heat pump selection. One solution to improve the system operating map is with the use of cascaded heat pumps, also known as booster heat pumps. In cascade systems, the condenser of one unit feeds the evaporator of the next.

A cascaded heat pump system includes the following elements:

- Low-temperature heat pump.
- Higher-temperature heat pump, also known as a "booster" heat pump.
- Intermediate loop connection from low-temperature condenser to high-temperature evaporator.

Designers should consider the following best practices when designing cascaded heat pump systems:

- The intermediate loop typically uses decoupled primary-secondary pumping to simplify flow management for each connected heat pump. This may also be referred to as "dual primary pumping".
- The intermediate loop volume must provide adequate loop time for the heat pump controls to react to changes in system operation. When the high-temperature heat pumps are installed in close proximity to the low-temperature heat pumps, intermediate loop volume may be small and a buffer tank may be required to increase system volume. Refer to the section "[Loop Volume and Buffer Tanks](#)," p. 35, for more information about loop volume.
- High-temperature and low-temperature heat pump selections must be coordinated so the low-temperature condenser operating conditions match those of the high-temperature evaporator. This dictates the intermediate loop operating conditions. Sufficient temperature margin must be included to account for transient changes in intermediate loop temperature.
 - A good starting point for the intermediate loop temperature is halfway between the system cooling supply and the boosted heating supply. This results in an equal split of compressor lift between the low-temperature and high-temperature heat pumps. This value may need to be adjusted to satisfy the design conditions of each heat pump.
- Include heat of compression when selecting cascaded heat pumps. The high-temperature evaporator capacity should match the low-temperature condenser capacity (not the low-temperature evaporator). This may result in different nominal tonnages for the high-temperature and low-temperature heat pumps.

Three examples are provided to illustrate the design flexibility that booster heat pumps provide within a cascaded heat pump system. These examples are designed to be “bolt on” optional configurations added to the base configuration of parallel central geothermal system.

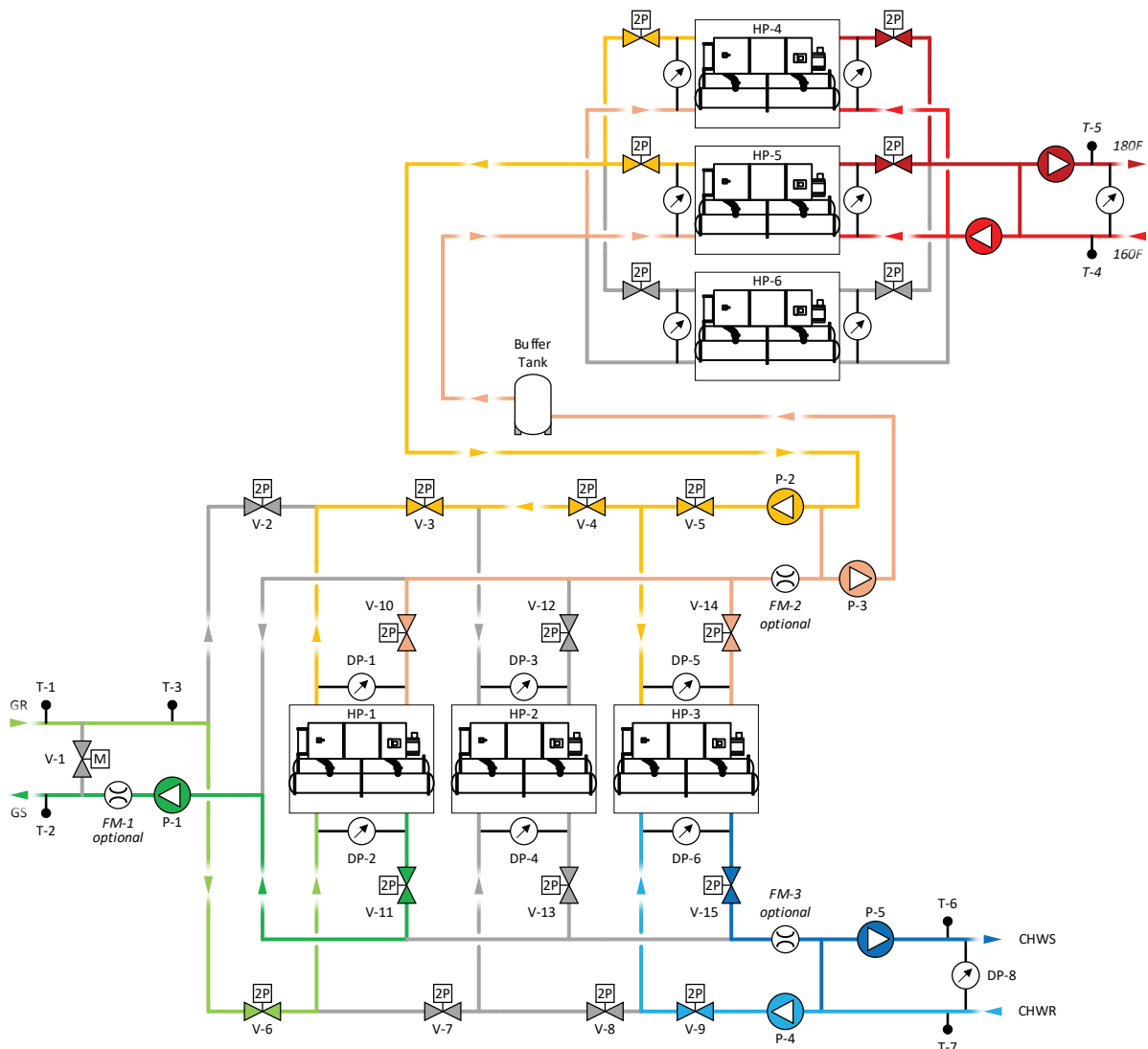
1. Full capacity cascade system for a 180°F (82 °C) heating supply temperature.
2. Dual temperature cascaded system for 210°F (99 °C) and 165°F (74 °C) heating supply temperatures.
3. Partial booster system where most of the heating capacity operates at 115°F (46 °C) and select loads operate at 180°F (82 °C).

Full Capacity Cascade System for a 180°F (82 °C) heating supply temperature

Figure 90, p. 114, uses multiple booster heat pumps to achieve full system heating capacity at 180°F (82 °C) heating supply temperature. For symmetry reasons, the number of high-temperature boosters matches the number of low-temperature heat pumps. The intermediate loop uses dual-primary pumping with a buffer tank installed on the entering evaporator pipe of high-temperature heat pump.

As the system transitions from cooling dominant to heating dominant, the boundary valves and ground loop mode valves operate exactly the same as the base configuration of parallel central geothermal system. The valves for the booster units open and close as a result of the chiller add/subtract sequence.

Figure 90. Parallel central geothermal system with 180°F (82 °C) a booster heat pumps providing full system capacity

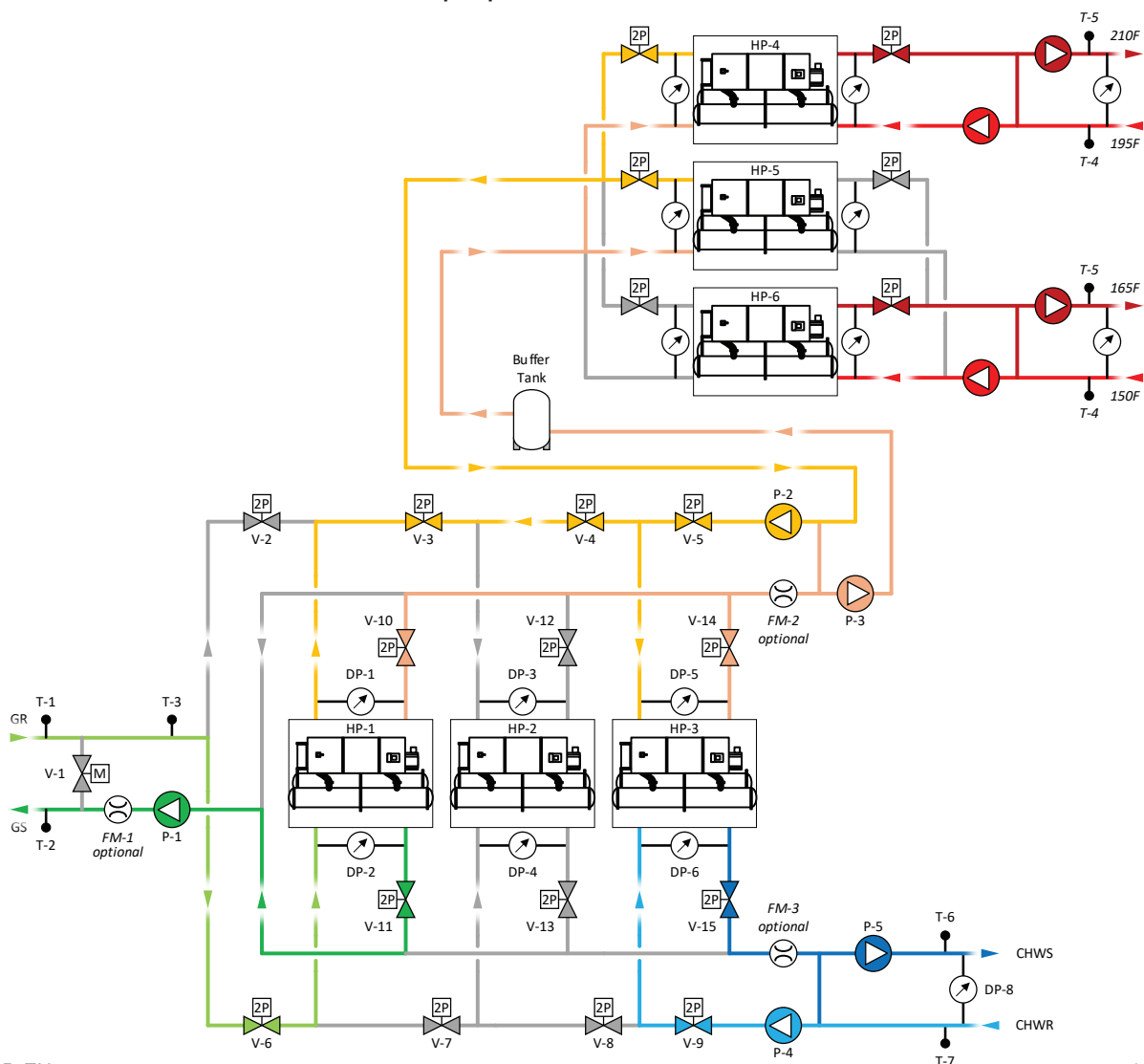


Dual temperature cascaded system for 210°F (99 °C) and 165°F (74 °C) heating supply temperatures

The next example system illustrates a dual-heating temperature system that provides both 210°F (99 °C) heating fluid and 165°F (74 °C) heating fluid (Figure 91). Dual-temperature heating systems limit the number of heat pumps that must be selected at higher operating temperatures. System efficiency is also greater due to less compressor lift on the reduced heating temperature loop.

The dual temperature cascaded example uses the same intermediate loop design as the previous example. As the system transitions from cooling dominant to heating dominant, the boundary valves and ground loop mode valves operate exactly the same as the base configuration of a parallel central geothermal system. The valves for the booster units open and close as a result of the chiller add/subtract sequence.

Figure 91. Parallel central geothermal system with dual temperature booster heat pumps



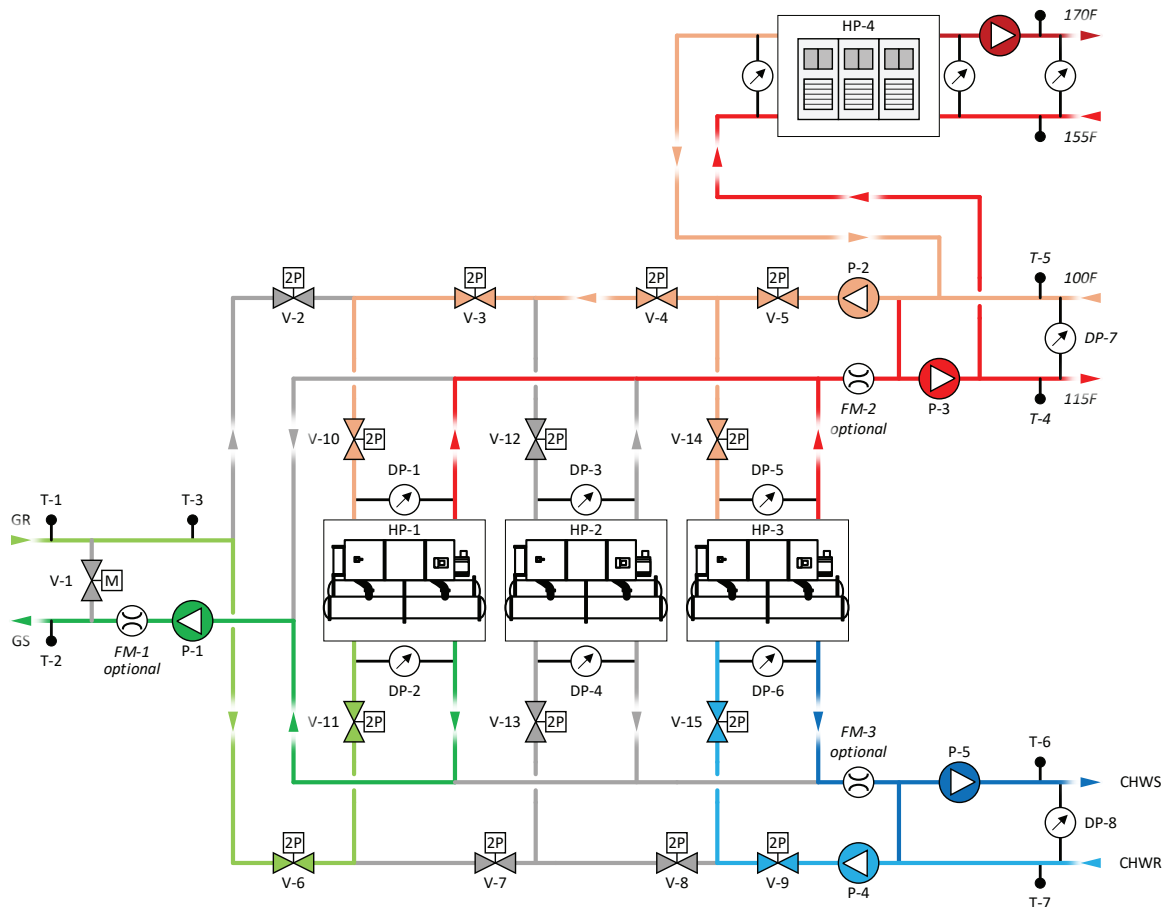
Partial booster system where most of the heating capacity operates at 115°F (46 °C) and select loads operate at 180°F (82 °C)

When a higher heating temperature is required for specific loads, a dedicated booster may be installed to serve those isolated loads. This further reduces equipment cost and improves system efficiency compared to designing the entire heating system for higher-temperature fluid.

Figure 92 uses a smaller-capacity modular heat pump to serve a single load at 180°F (82 °C). The rest of the heating loop is served by lower-temperature heating fluid at 115°F (46 °C).

The heating supply loop of this example provides sufficient loop volume to avoid an additional buffer tank in the intermediate loop. The 115°F (46 °C) heating distribution pumps in this example provide sufficient differential pressure to satisfy the high-temperature booster evaporator, eliminating one set of pumps.

Figure 92. Parallel central geothermal system with partial booster capacity



Appendix

Glossary

AHRI. Air-Conditioning, Heating, and Refrigeration Institute (www.ahrinet.org).

Airside Economizer. A method of free cooling that involves using cooler outdoor air for cooling instead of recirculating warmer indoor air.

Air-to-Water Heat Pump (AWHP). A unit that heats or cools fluid by transferring energy between the fluid and the air via a refrigeration circuit and often contains a reversing valve. AWHPs may contain more than one refrigeration circuit and can be configured as a two-pipe or four-pipe unit (see multi-pipe heat pump). Two pipe AWHPs that either cool or heat include a reversing valve and four-pipe units that can cool/heat, cool only, or heat only do not have a reversing valve.

ASHRAE. American Society of Heating, Refrigerating and Air Conditioning Engineers (www.ashrae.org).

Auxiliary Boiler. A secondary or supplemental boiler used to provide steam or hot water when the main boiler or primary heating system cannot meet the full demand or is offline.

Auxiliary Cooler. A supplemental cooling device that provides additional cooling capacity when the main cooling system (such as the primary chiller, cooling tower, or refrigeration unit) cannot meet the full demand or is offline.

Borefield. A ground coupling heat source and sink field consisting of tubing buried in ground in either vertical bore holes or horizontal trenches. The borefield transfers heat energy to and from the ground and in many cases, acts as a “thermal battery” for the geothermal system.

Borehole. A narrow shaft bored in the ground, either vertically or horizontally, in which a U-tube is inserted as part of a ground heat exchanger.

Building Automation System (BAS). A centralized control and monitoring system for a building.

Central Geothermal System. One or more heat pump chiller(s) is centrally located in a mechanical equipment room. The heat pump chiller(s) provide hydronic heating and cooling to terminal devices throughout the building.

Changeover System. Hydronic HVAC system that switches between heating and cooling mode.

Compressor Lift. The difference in temperature between condenser leaving fluid and evaporator leaving fluid. Larger differences mean the compressor must work harder to transfer heat, consuming more power (less efficient).

Cooling Priority/Cooling Dominant. The building is operating with greater cooling load than heating load. The building is net heat (Btu) excess. Excess energy is rejected to the geothermal system or other heat rejection equipment such as cooling tower if so equipped.

Cooling Tower. An enclosed device for evaporatively cooling water by contact with air.

Distribution Loop. Part of the water loop that connects to the WSHPs.

Distributed Geothermal System. Uses smaller heat pumps distributed through the building. The ground loop is piped to each of the heat pumps. The heat pumps produce cool air or warm air to satisfy the zone temperature.

Four-Pipe Distribution. Hydronic distribution system that includes separate supply and return lines for cooling loop and heating loop. Four-pipe distribution allows heating loads and cooling loads to operate simultaneously.

Geothermal System. HVAC system that uses the earth as a heat sink when cooling and a heat source when heating.

Ground Heat Exchanger. A closed system of looped, polyethylene pipes that are buried in the ground in a vertical, horizontal, or spiral pattern.

Ground-Coupled Heat Pump (GCHP). Fluid is pumped through a closed loop ground heat exchanger buried in soil to source or sink heat for the heat pumps.

Ground Loop. A fluid loop that connects to the ground heat exchanger to reject or source heat. This may also be referred to as a "source loop." Types of ground loops include GCHP, GWHP, and SWHP.

Ground Loop Return. Fluid leaving the ground heat exchanger.

Ground Loop Supply. Fluid going into the ground heat exchanger.

Ground-Water Heat Pump (GWHP). Water is pumped out of the ground and delivered to a heat pump (or an intermediate heat exchanger) where heat is absorbed or rejected before the groundwater is returned via re-injection well.

Ground-Source Heat Pump (GSHP). A broad term referencing any system that uses the ground, groundwater or surface water as the geothermal heat source and sink.

Heat Pump. A device that transfers heat from one substance to another substance. It includes the basic refrigeration components of a compressor, condenser, evaporator, and expansion device. The difference is that it can also reverse the refrigeration cycle to perform heating as well as cooling.

Heat Pump Chiller. Refrigerating machines that can be controlled to provide either fluid heating as a primary function or cooling as a primary function with simultaneous heating. The function is dependent on what is needed for the application at a particular point in time. When a unit's purpose switches between cooling and heating and it does not have a reversing valve, depending on application, such a unit may be referred to as a "Non-Reversible Heat Pump."

Ground Loop Supply and Return

The terms "supply" and "return" can be confusing for ground loops. Not all engineers agree on which one goes to the ground and which one comes from the ground. The terminology for open loop "supply well" and "re-injection well" adds further confusion. This manual relies upon the naming conventions from the 2023 *ASHRAE Handbook of HVAC Applications*, chapter 35. While these terms aren't explicitly defined in the handbook, this convention is used throughout the chapter.

Heat Recovery Unit. A refrigeration unit that uses waste heat from other processes or loads to create beneficial heat output. Heat recovery units require simultaneous heating and cooling loads to operate. Units that collect heat from cooling loop return provide beneficial cooling output in addition to heat.

Heating Priority/Heating Dominant. The building is operating with greater heating load than cooling load. The building is net heat (Btu) deficit. Deficit energy is sourced from the geothermal system or other heat addition equipment such as boiler or solar thermal panels.

Hydronic Changeover. System or equipment that uses hydronic valve operation to switch between heating mode and cooling mode.

IGSHPA. International Ground-Source Heat Pump Association (www.igshpa.org).

Modular Heat Pump. A heat pump consisting of multiple modules that function together as a bank. Each module includes an independent refrigerant circuit. In some cases, a single module can be used standalone.

Modular Multi-Pipe Heat Pump. A multi-pipe heat pump that uses multiple modules that function together as a bank.

Multi-Pipe Heat Pump. A hydronic refrigeration unit that provides heating and cooling output with independent control of the heating and cooling temperatures. Multi-pipe heat pumps include three heat exchangers; one for cooling, one for heating, and one that can sink or source heat as needed to achieve thermal energy balance. Air-source multi-pipe heat pumps are 4-pipe while water-source multi-pipe heat pumps are 6-pipe.

Packaged Heat Pump. A complete heat pump, typically consisting of a single evaporator and condenser. Multiple compressors or refrigerant circuits may be connected to the evaporator and condenser. Packaged heat pumps are installed as a standalone unit.

Refrigerant Changeover. System or equipment that uses refrigerant reversing valves to switch between heating mode and cooling mode.

Reversing Valve. The component of a heat pump that allows it to perform heating as well as cooling. In the heating mode, refrigerant vapor from the compressor is diverted, by the reversing valve, to the refrigerant-to-air heat exchanger.

Surge. A condition of unstable fan operation where the air alternately flows backward and forward through the fan wheel, generating noise and vibration.

Surface-Water Heat Pump (SWHP). A heat-pump system that uses surface water in a lake, pond or river as the geothermal heat source and sink. Similar to GCHP or GWHP, however, the thermal characteristics of surface water bodies are quite different than those of the ground or groundwater.

Thermal Conductivity. Time rate of heat flow through a homogeneous material, expressed in units of Btu/hr•ft•°F (W/m•°K). This property characterizes the rate at which heat transfers from the ground heat exchanger to the surrounding soil.

Two-Pipe Distribution. Hydronic distribution system that includes a supply line and a return line that can be used for heating or cooling, but not both simultaneously.

u-tube. The component of a ground heat exchanger that is inserted into the borehole. It is typically constructed of two continuous sections of high-density polyethylene (HDPE) with a factory-attached 180-degree fitting (U-bend) at the bottom.

Variable Frequency Drive (VFD). A device that controls motor speed by varying the frequency and voltage of the power supplied to the motor.

Water Loop. A hydronic loop that is piped to the individual WSHP units and includes a means for heat addition and heat rejection, depending on operating conditions.

Water-to-Water Heat Pump (WWHP). A unit that controls to a heating or cooling temperature by transferring heat between two fluid sources and it may or may not include a reversing valve to change to roles of the heat exchanger. These units can be used as a dedicated heat recovery or as a booster heat pump in a cascade system.

Well Field. Wells used in ground-water systems. One or more wells from which water is pumped to serve as a heat source and sink for a geothermal system. The water may be re-injected into the ground or dumped to a storm drain.


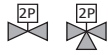
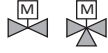



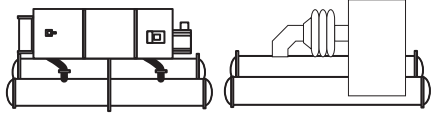




Water-Source Heat Pump (WSHP). A type of heat pump that transfers heat from air to water and vice versa.

Zone. One occupied space or several occupied spaces with similar characteristics (thermal, humidity, occupancy, ventilation, building pressure).

Equipment Designations and Symbols










Piping diagrams include the following symbols and designators:

Table 37. Equipment designators and symbols

Equipment type	Designator	Symbol
Pump	P-x	
Two position valve	V-x	
Modulating valve	V-x	
Temperature sensor	T-x	
Pressure sensor	PT-x	
Flow meter	FM-x	
Water-to-water heat pump chiller	HP-x	
Air-to-water heat pump chiller	HP-x	
Modular heat pump chiller	HP-x	
Auxiliary boiler	BLR-x	
Auxiliary cooler	CT-x	

Piping diagrams use the following labels and color conventions:

Table 38. Piping color conventions

Color	Label	Description
	CHWS	Chilled water supply
	CHWR	Chilled water return
		Dark blue signifies <40°F, glycol may be required
	GS	Ground supply (into ground)
	GR	Ground return (return from ground)
		Dark green signifies the cooler fluid
	HWR	Hot water return
	HWS	Hot water supply
	N/A	Used for base piping and pipes with no flow

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