Introduction

This application guide is written to assist the designer in Geothermal heat pump design. It is a companion guide to McQuay's Catalog 330-1, ***Water Source Heat Pump Design Manual,*** which discusses Boiler/Tower heat pump design. It can be downloaded from www.mcquay.com or contact your local McQuay representative.

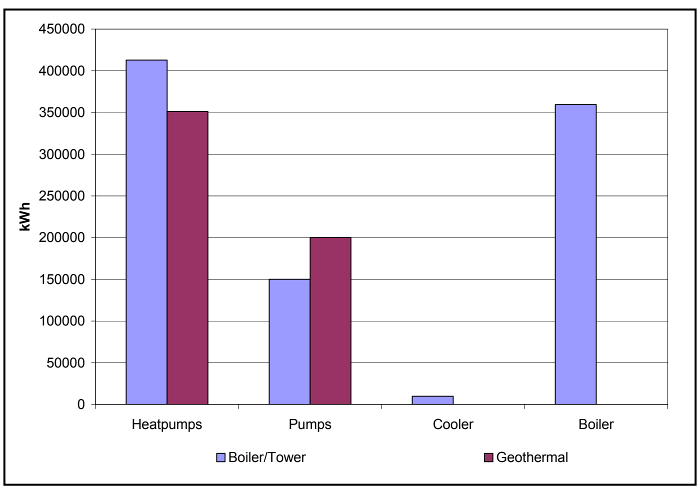
For the most comprehensive guide to Geothermal heat pump design, it is recommended that designers refer to *Ground-Source Heat Pump Systems: Design of Geothermal Systems for Commercial and Institutional Systems*, available from the American Society Of Heating, Air-conditioning and Refrigeration Engineers (ASHRAE) at www.ashrae.org.

Why are Geothermal Heat Pumps So Effective?

It is not unusual to hear how Geothermal water source heat pump systems are very energy efficient, but what is it that makes them so efficient? Both Boiler/Tower and Geothermal systems use basically the same heat pump equipment and the COPs (Coefficient of Performance) are similar when rated at the same conditions. A Geothermal system's summer design conditions are close to a Boiler/Tower system's (90°F loop design temperature is common), but the winter design temperature is often much lower. While it is true that Geothermal systems do not have a boiler or a cooling tower, there is a large water pressure drop in the ground loop that requires a large pump horsepower.

One advantage of the system is the closed loop water source heat pump design. The concept allows energy that is not required in some areas of the building (cooling load) to be moved and used in areas that do require energy (heating load). For many applications, water source heat pump systems match or exceed the performance of even the most sophisticated VAV air systems.

Figure 1 – Comparison of Boiler/Tower vs. Geothermal Heat Pumps



Loop Operating Temperatures

While it is not unusual for Geothermal and Boiler/Tower summer design loop temperatures to be around 90°F, Geothermal systems can have a winter design condition below freezing (25°F to 30°F) in cooler climates. Most Boiler/Tower systems are designed for 60°F to 70°F.

The real energy savings do not come from design conditions, but from part load operating performance. Even in colder climates, most heat pumps used in commercial applications operate in cooling most of the time. This is particularly true for units serving core areas of a building. The colder the loop is in cooling, the better the heat pump performance (usually measured as EER or Energy Efficiency Ratio). Because Boiler/Tower systems maintain the loop temperature above 60 to 70°F, the heat pumps have an EER around 22. Geothermal systems allow the loop temperature to be potentially much cooler and the EER for the heat pumps can be as high as 36.

In addition, the loop temperature over the course of the year is much cooler for Geothermal systems. Boiler/Tower systems will operate at design conditions as soon as there is a net heat gain in the building which causes the loop temperature to rise. The cooling tower controls will not start to reject heat until the loop temperature is near the cooling setpoint.

Evaluating the performance over the entire year requires annual energy analysis. Software tools such as McQuay's Energy Analyzer™ can be used to track the energy consumed by heat pumps in Boiler/Tower and Geothermal systems. Figure 1 shows annual energy usage for a 160,000 ft² high school in Minneapolis. The Geothermal system uses 60% of the energy used by the Boiler/Tower system. In this case, the savings are over $13,000/year.

Cooling Tower and Boiler Energy

Boiler/Tower systems require some form of cooling tower (Either a closed circuit evaporative cooler or an open cooling tower with a heat exchanger). These devices reject heat to the atmosphere based on the ambient wet bulb temperature. They consume power in two ways. First, their fans and pumps use electricity. Second, their water pressure drops must be accounted for when sizing the circulating pumps. Figure 1 shows the annual energy usage for a closed circuit cooling tower to be 958 kWh/yr.

Boilers are used in Boiler/Tower systems to maintain the loop temperature above the minimum setpoint. Most of the required heat in a heat pump system comes from other heat pumps on the loop operating in cooling. The actual number of hours a Boiler/Tower loop requires supplemental heat is very small. In the example in Figure 1, the boiler actually ran only 1506 hours, mostly on weekends.

When the boiler is required, it will consume either natural gas or electricity. Also, the boiler adds a pressure drop to either the main loop or to a tertiary pump. The latter has the advantage that it only uses power when the boilers are required. Figure 1 shows the energy use by the boiler to be 1,227,000 kBtu/yr (359,000 kWh/yr).

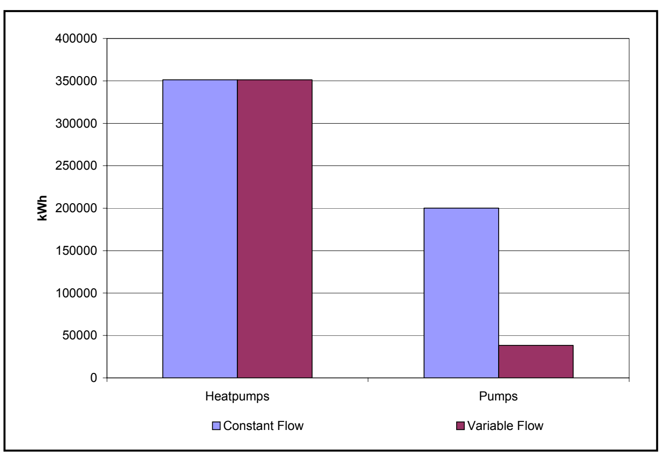
It is not uncommon to use boilers for other heating loads in addition to maintaining the minimum loop temperature (i.e. the ventilation load and entrance heaters). In evaluating Geothermal and Boiler/Tower systems, how these loads are accommodated should be carefully considered.

Pump Work

At first glance, Geothermal systems would appear to require significantly larger pumps to meet the pressure drop from the ground loop. However, geothermal systems do not have a cooling tower or a boiler pressure drop. In addition to the loops being carefully designed to minimize pressure drops, the use of reverse return piping, common headers and carefully sized piping can all help to reduce the pressure drop. It is not unusual for a Geothermal system to be under 100 ft. of head and not significantly greater than a Boiler/Tower system.

Geothermal systems tend to be designed with higher flow rates that result in higher pump work than Boiler/Tower systems.

Figure 2 – Constant vs. Variable Flow



ASHRAE Standard 90.1-2001, Energy Standard for Buildings Except Low Rise Residential Buildings, requires hydronic systems with a total pump power exceeding 10 hp to be variable flow (6.3.4), and that each water source heat pump have a two position isolating valve that closes when the compressor is not operating (6.3.4.4). Figure 2 shows the annual energy savings from switching to variable flow for the example shown in Figure 1. Variable flow offers an additional $6,000/year in savings.

The pump work is very high in constant flow heat pump systems because it is based on the sum of the flow rate requirements of all the connected heat pumps and the flow must be provided 24 hours a day. Switching to variable flow lowered the pump work by 80% in this example.

It is not recommended that the design flow rate or pipe size be reduced for variable flow systems as it is likely that most of the heat pumps may operate at the same time for a short period. This is long enough to cause nuisance trips because heat pumps cannot operate for any duration without flow.

Ventilation Load

Ventilation loads are often a significant load throughout the year. Water source heat pumps usually have a dedicated system for heating and cooling the ventilation air. How effective this system is will dictate the overall performance of the building. Geothermal systems will often have advanced ventilation systems that provide excellent energy savings and improve the overall building operating cost. Ventilation systems are discussed in detail in ***Ventilation System Design*** (see page 33).

Other Benefits

In addition to the energy and operating cost savings, Geothermal systems offer many other advantages. Because there are no cooling towers and boilers, there is no need for sump heaters, tower water chemicals and make-up water.

Decentralized Design

Each water source heat pump is in close proximity to the zone it serves, avoiding the large duct runs associated with central air systems. An equipment failure only affects the zone where the failed unit is located. Central system equipment failures can drastically affect large portions of the building.

Equipment can be changed to meet the specific needs of an occupant (i.e. in a retail environment, the unit can be sized to meet the load of a new tenant). Individual power metering is possible, allowing occupants to control and pay their own energy costs. As the building is constructed, only a minimum amount of equipment needs to be provided until an occupant is found and the tenant design complete.

Easy To Service

Water source heat pumps are easy to service and do not require specialized training. The owner has many more options regarding maintenance and service. The refrigerant charges are small, which helps minimize safety requirements within the building.

Small Mechanical Rooms

Water source heat pump systems generally require smaller mechanical rooms than other HVAC systems. Geothermal system mechanical rooms are even smaller, requiring space for only the circulating pumps, the main header and some chemical treatment equipment. This frees up more useable/leasable space for tenants or occupants.

Figure 3 Typical Heat Pump Arrangements

Flexible Equipment

Heat pumps come in all shapes and sizes to meet space requirements. Sizes range from ½ ton to 30 tons. They can be located above the ceiling, in a closet or in the occupied space.

Indoor Air Quality (IAQ)

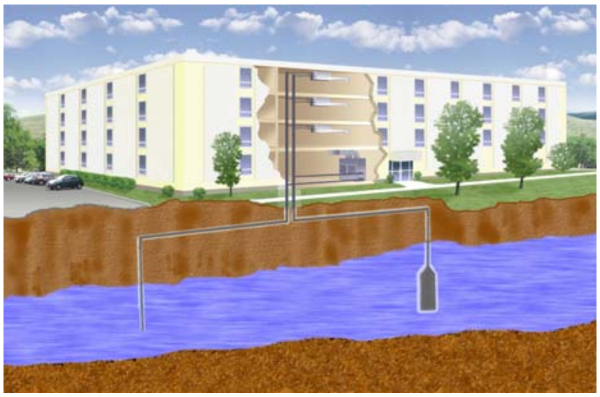
Heat pump systems with properly designed ventilation systems offer a good solution for indoor air quality (IAQ). The units can be supplied with double-sloped, cleanable drain pans and closed cell insulation. A proper ventilation system, along with the heat pumps, can help control moisture for good IAQ.

Loop Design Theory

Loop Types

A ground loop is a heat exchanger that either extracts or adds heat to the ground. The ground itself is not a perfect heat sink/source because the energy added to the ground by the loop can change its temperature over time. The principles of this interaction are common in all loop types and will be discussed here. Geothermal systems come in several different configurations, each with its own strengths and weaknesses. These are discussed below.

Figure 4 – Open Loop



Open vs. Closed Loop

Open loop systems draw ground water directly into the building and heat/cool the heat pumps with it. The system requires sufficient ground water to meet the needs of the building. Ground water often has minerals and other contaminants in it that detrimentally affect the equipment.

Open loop systems that use lake water are also available, but should use filtration equipment or secondary heat exchangers to deal with contaminates. Lake water, used in a open loop application, should be used in climates where the entering water temperature is above 40 degrees F. The ground must have the capacity to take open loop system discharge. These cannot be used below 40°F without the risk of freezing. In addition, open loop systems must allow for the increased pump head from the lake/ground water level to the heat pumps. Open loop systems are not common on commercial and institutional applications and will not be covered here.

Closed loop systems have a dedicated fluid loop that is circulated through the ground or pond in order to exchange energy. The ground/pond water and loop water do not mix. Closed loop systems are further broken down into loop types.

Figure 5 - Horizontal Loop

Horizontal Loop

A horizontal loop runs piping parallel and close to the surface. The undisturbed ground temperature often changes seasonally depending upon where the loops are installed. Horizontal loops are easier to install but require significantly more area (approximately 2500 ft²/ton) than other loop types.

Figure 6 – Vertical Loop

Vertical Loop

Vertical loops run perpendicular to the surface and the holes can be several hundred feet deep. At these depths, the undisturbed ground temperature does not change throughout the year. Vertical loops only require approximately 250 to 300 ft²/ton.

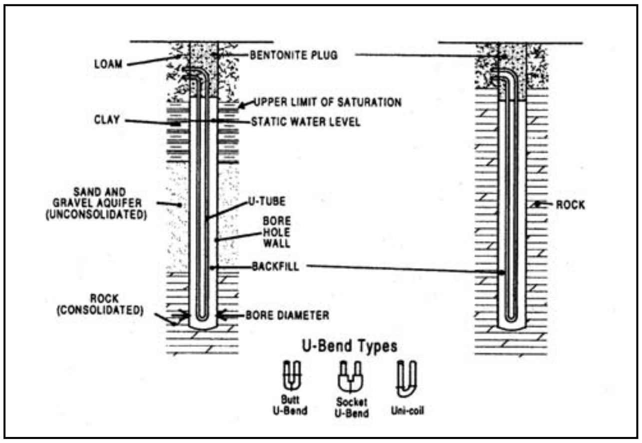
Figure 7 – Surface Water Loop

Surface Water Loop

Surface water or pond loops use a body of water as the heat sink. Heat escapes the water through surface evaporation, so the process is closely connected to pond temperature and ambient wet bulb. In winter, when the pond could be frozen, heat transfer is dominated by contact between the loops, the bottom water and the soil surface at the bottom of the pond.

Ground Loop Fundamentals

Figure 8 – Typical Vertical U Tube Installation[1]



The ground loop is a heat exchanger that is similar to a cooling coil or an evaporator in a chiller. The goal is to transfer energy from the heat pump loop fluid to/from the ground.

The purpose of loop design is to estimate the required loop length. This is best done with computer software, but a basic understanding of the process is helpful. The heating and cooling loads provide the designer with the energy transfer rates for sizing the loop. The design supply fluid temperatures must be estimated. The larger the loop for a known load, the cooler the supply fluid temperature will be. Lower fluid temperatures improve

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the heat pump performance and capacity. The designer must find a balance between heat pump fluid supply temperature and the capital cost of the ground loop.

At steady-state conditions, there is heat transfer from the heat pump fluid to the ground. The temperature difference between the ground and the fluid in the loop provides the impetus for the energy to move. The resistance of the pipe, the grout and the ground restrict the energy movement as follows:

$Q_c = L(t_g - t_w)/R$

Where

Q_c is the heat load (Btu/hr)

L is the pipe length (feet)

t_g is the ground temperature

t_w is the fluid temperature

R is the thermal resistance to heat transfer.

The challenge in loop design is that the ground temperature does not stay constant. For horizontal loops, where the pipe is near the surface, the ground temperature can change seasonally with the weather. In all cases, the loop itself affects the ground temperature. For loop design, it is common to break the effects into three parts:

- **Long Term Effect**. This is the change in the ground temperature over many years. If the building has a net heat gain or a net heat loss, the ground temperature will change. The more densely placed the boreholes are, the larger the effect. Ground water moving through the bore hole field can help remove energy and limit the long-term temperature change. For commercial applications, the ground temperature generally climbs.

  An example of long term effect would be a 6°F average ground temperature rise over 10 years due to the heat added to the borehole field. The penalty will not be present during the first year, but the heat build up will change the system performance over time.

- **Annual Effect**. Over the course of a year, the heat load on a bore field will change and this will affect the ground temperature on a monthly basis. It is this "flywheel" effect that can actually cause the warmest ground loop temperature to occur after the peak load has occurred.

- **Short Term Effect**. The actual load on the loop will affect the fluid supply temperature. For example, if the building were shut down, the fluid temperature would quickly become the ground temperature. However, the loop temperature would be the ground temperature plus the design approach at design load. The actual hourly load also affects the borehole field's ability to dissipate heat. Therefore, the ground temperature will change with the hourly load. Most loop sizing software group the design day loads into four-hour intervals rather than using all 24 hours.

These three effects must be estimated to find the required pipe length. The length may be established by the winter heating load requirement or the summer cooling load requirement. If a winter peaking load establishes the length, the designer should go back and evaluate the cooling performance with the longer length. This will improve the summer performance and may allow smaller heat pumps to be used for some spaces.

Borehole Thermal Resistance

Many factors affect the thermal resistance of the ground loop. These include the pipe properties, flow rate, backfill and grout properties, soil properties and fluid properties.

Pipe Properties

Table 1 – Equivalent Diameters and Thermal Resistances for Polyethylene U-Tubes[2]

U-Tube Dia.	SDR or Schedule	Pipe (Bore) Thermal Resistance (h•ft•F°/Btu)			
		For Water Flows Above 2.0 US gpm	**20% Prop. Glycol Flow 3.0 US gpm**	**20% Prop. Glycol Flow 5.0 US gpm**	**20% Prop. Glycol Flow 10.0 US gpm**
¾ in. (0.15 ft)	SDR 11	0.09	0.12	NR	NR
	SDR 9	0.11	0.15	NR	NR
	Sch 40	0.10	0.14	NR	NR
1.0 in. (0.18 ft)	SDR 11	0.09	0.14	0.10	NR
	SDR 9	0.11	0.16	0.12	NR
	Sch 40	0.10	0.15	0.11	NR
1 1/4 in. (0.22 ft)	SDR 11	0.09	0.15	0.12	0.09
	SDR 9	0.11	0.17	0.15	0.11
	Sch 40	0.09	0.15	0.12	0.09
1 1/2 in. (0.25 ft)	SDR 11	0.09[1]	0.16	0.15	0.09
	SDR 9	0.11[1]	0.18	0.17	0.11
	Sch 40	0.08[1]	0.14	0.14	0.08

Based on using borehole cuttings for backfilling around u-tube. Use **Table 2** corrections for other conditions.
[1] Water flow must be at least 3.0 US gpm to avoid laminar flow for these cases.

Table 1 shows thermal resistances for four common pipe sizes. Avoiding laminar flow at design conditions is important to provide good heat transfer. For water, the flow rate should be at least 2.0 US gpm for ¾" through 1 ¼ " pipe, and at least 3 US gpm for 1 ½"pipe to avoid laminar flow.

Backfill and Grouts

The backfill also plays a major part in performance. Air gaps or separation should be avoided as air is a natural insulator. Grouting is the most common material for backfill. It can seal the borehole off from surface water penetration. Standard grout actually has a poor conductivity, so the bore hole diameter should be minimized (Approximately 5" diameter) to limit the grout's affect. There may be local code requirements to grout the entire borehole, or the borehole may penetrate multiple aquifers that need to remain isolated.

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Table 2 – Thermal Resistance Adjustments For Other Borehole Backfills or Grouts[3]

(Add value to Base Resistances in)

Natural Soil Cond.	0.9 Btu/h•ft•F°		1.3 Btu/h•ft•F°			1.7 Btu/h•ft•F°	
Backfill or Grout Conductivity	**0.5 Btu/h•ft•F°**	**2.0 Btu/h•ft•F°**	**0.5 Btu/h•ft•F°**	**1.0 Btu/h•ft•F°**	**2.0 Btu/h•ft•F°**	**0.5 Btu/h•ft•F°**	**1.0 Btu/h•ft•F°**
4 in. Bore							
¾ in. U-tube	0.11 (NR)	-0.05	0.14 (NR)	0.03	-0.02	0.17 (NR)	0.05
1 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.13 (NR)	0.04
5 in. Bore							
¾ in. U-tube	0.14 (NR)	-0.06	0.18 (NR)	0.04	-0.04	0.21 (NR)	0.06
1 in U-tube	0.11 (NR)	-0.04	0.14 (NR)	0.03	-0.02	0.16 (NR)	0.05
1 1/4 in U-tube	0.06	-0.03	0.09	0.02	-0.02	0.12 (NR)	0.04
6 in. Bore							
¾ in. U-tube	0.18 (NR)	-0.07	0.21 (NR)	0.04	-0.05	0.24 (NR)	0.07
1 in U-tube	0.14 (NR)	-0.06	0.17 (NR)	0.03	-0.04	0.21 (NR)	0.06
1 1/4 in U-tube	0.09	-0.04	0.12 (NR)	0.03	-0.02	0.15 (NR)	0.05
1 1/2 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.11 (NR)	0.04

(NR) Not Recommended
Air Gaps add 0.2 t o0.4 h•ft•F°/Btu to Bore Resistance
Note some adjustments are negative, which indicates a thermal enhancement and a lower net thermal resistance compared to natural backfills.

Table 3 shows the thermal conductivities for enhanced grouts. Enhanced grouts can significantly improve the borehole performance, which can lead to fewer or shallower boreholes. However, it is more costly. Each project is unique and a job-by-job analysis is required to evaluate whether enhanced grouts will actually reduce the construction cost.

Table 3 – Thermal Conductivities of Typical Grouts and Backfills[4]

Grouts and Additives	k (Btu/h•ft•F°)	Thermal Enhanced Grouts	k (Btu/h•ft•F°)
20% Bentonite	0.42	20% Bentonite – 40% Quartzite	0.85
30% Bentonite	0.43	30% Bentonite – 30% Quartzite	0.70-0.75
Cement Mortar	0.40-0.45	30% Bentonite – 30% Iron Ore	0.45
Concrete @ 130/150 lb/ft³	0.60-0.80	60% Quartzite – Flowable Fill (Cement + Fly Ash+ Sand)	1.07
Concrete (50% quartz sand)	1.1-1.7		

Soil Properties

The thermal conductivity of the soil at the site is required to estimate the ground loop performance. For large (over 50 tons) projects, the soil should be tested (refer to ***Ground Testing***, page 26). The advantage to testing is that more accurate soil data will allow the designer to minimize the safety factor and reduce the number of holes. The savings from the reduced number of holes should more than pay for the test.

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Table 4 – Thermal Conductivity and Diffusivity of Sand and Clay Soils[5]

Soil Type	Dry Density (lb/ft³)	5% Moist		10% Moist		15% Moist		20% Moist	
		k	α	k	α	k	α	k	α
Coarse 100% Sand	120	1.2-1.9	0.96-1.5	1.4-2.0	0.93-1.3	1.6-1.2	0.91-1.2	-	
	100	0.8-1.4	0.77-1.3	1.2-1.5	0.96-1.2	1.3-1.6	0.89-1.1	1.4-1.7	0.84-1.0
	80	0.5-1.1	0.60-1.3	0.6-1.1	0.60-1.1	0.6-1.2	0.51-1.0	0.7-1.2	0.52-0.90
Fine Grain 100% Clay	120	0.6-0.8	0.48-0.64	0.6-0.8	0.4-0.53	0.8-1.1	0.46-0.63	-	-
	100	0.5-0.6	0.48-0.58	0.5-0.6	0.4-0.48	0.6-0.7	0.37-0.48	0.6-0.8	0.41-0.55
	80	0.3-0.5	0.36-0.6	0.35-0.5	0.35-0.5	0.4-0.55	0.34-0.47	0.4-0.6	0.30-0.45

Thermal Conductivity (k) - Btu/h•ft•F° and Thermal Diffusivity (α) - ft²/day
Coarse grain = 0.075 to 5 mm – Fine Grain less than 0.075 mm

Table 4 shows the thermal properties for sand and clay soils, which range from 0.3 to 1.9 Btu/h•ft•F°. Most soil is a combination of fine and coarse grain. A Sieve analysis can be used to determine the percentage of each so that a weighted average can be developed to find an overall conductivity. Moisture content is a major factor, but sand or clay do not need to be heavily saturated to provide good conductivity.

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***Table 5 – Thermal Properties of Rocks At 77°F*[6]**

Rock Type	%[1] Occurrence in Earth's Crust	k - All[2] Ther. Con. Btu/h•ft°F	K - 80%[3] Ther. Con. Btu/h ft•°F	c_p Spec. Heat Btu/lb-°F	ρ Density lb/ft^3	α (k/ρ c_p) Ther. Diff. ft^2/day
Igneous Rocks						
Granite (10% Quartz)	10.4	1.1—3.0	1.3-4.9	0.21	165	0.9-4.3
Granite (25% Quartz)			1.5-2.1			1.0-1.4
Amphibolite	42.8	1.1-2.7	1.5-2.2		175-195	
Andesite		0.8-2.8	0.9-4.4	0.12	160	1.1-4.7
Basalt		1.2-1.4		0.17-0.21	180	0.7-0.9
Gabbro (Cen. Plains)		0.9-1.6		0.18	185	0.65-1.15
Gabbro (Rocky Mtns.)		1.2-2.1				0.85-1.5
Diorites	11.2	1.2-1.9	1.2-4.7	0.22	180	0.7-1.0
Grandiorites		1.2-2.0		0.21	170	0.8-4.3
Sedimentary Rocks						
Claystone		1.1-4.7				
Dolomite		0.9-3.6	1.6-3.6	0.21	170-475	1.1-2.3
Limestone		0.8-3.6	1.4-2.2	0.22	150-475	1.0-4.4
Rock Salt		3.7		0.20	130-435	
Sandstone	1.7	1.2-2.0		0.24	160-470	0.7-4.2
Siltstone		0.8-1.4				
Wet Shale (25% Qrtz.)	4.2	0.6-2.3	1.0-4.8	0.21	130-165	0.9-1.2
Wet Shale (No Qrtz.)			0.6-0.9			0.5-0.6
Dry Shale (25% Qrtz.)			0.8-4.4			0.7-1.0
Dry Shale (No Qrtz.)			0.5-0.8			0.45-0.55
Metamorphic Rocks						
Gneiss	21.4	1.0-3.3	1.3-2.0	0.22	160-175	0.9-1.2
Marble	0.9	1.2-3.2	1.2-1.9	0.22	170	0.8-1.2
Quarzite		3.0-4.0		0.20	160	2.2-3.0
Schist	5.1	1.2-2.6	1.4-2.2		170-200	
Slate	.	0.9-4.5		0.22	170-475	0.6-0.9

Table 5 lists the thermal properties for rock. Again, there is a wide variation in performance. Because of its high porosity, rock generally has lower performance. The 80% range is more conservative and is recommended unless the designer has detailed information.

Effects of Ground Water

Ground water movement through the bore hole field can have a large impact on its performance. Ground water recharge (vertical flow) and ground water movement (horizontal flow) can all carry away large amounts of energy. Evaporation can also cool the surface soil and improve horizontal loop performance.

Fluid Properties

In colder climates, where the supply loop temperature may be less than 40ºF, antifreeze will be required. Antifreeze will change the properties of the loop fluid. Refer to APPENDIX 1 for properties of various antifreezes. Adding antifreeze will generally lower the thermal capacity of the fluid and increase the viscosity. The latter will increase pump work. Also, the Reynolds number will decrease and raise the flow rate at which laminar flow begins. To offset these effects, the design flow

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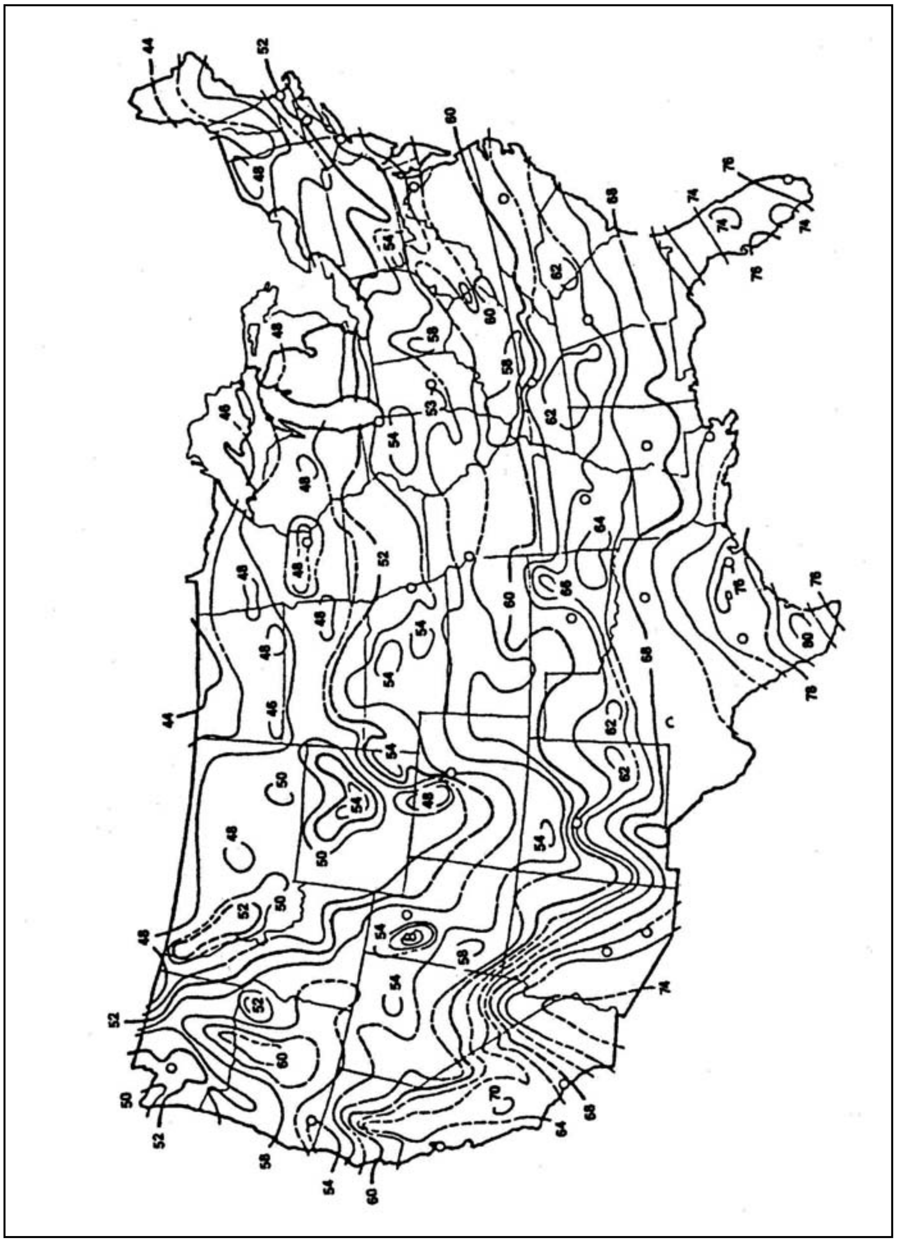
rate may need to be increased. Most loop design software programs include a range of antifreezes and take into account the change in properties.

Ground Temperature

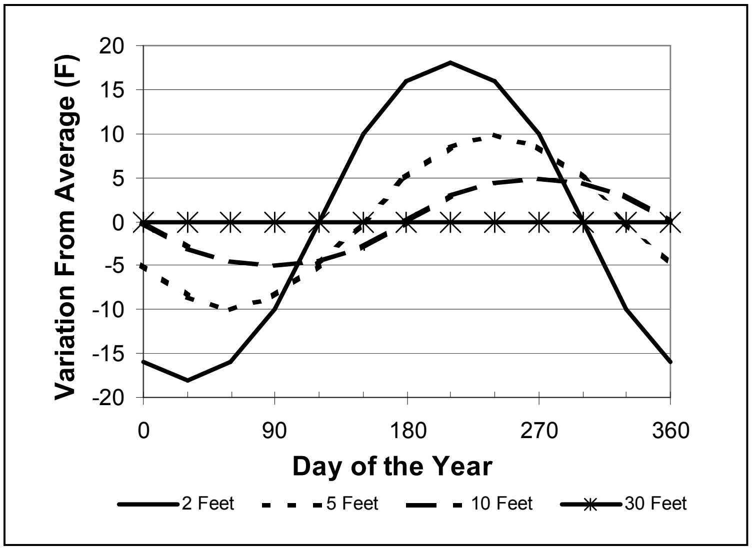
Undisturbed ground temperature is best obtained from local water well logs and geological surveys. Figure 9 shows the approximate ground water temperatures in the USA. The undisturbed ground temperature will remain constant throughout the year below 30 ft. Above 30 ft., the ground temperature will change with the season. ***Appendix 1 – Ground Temperatures***, page 36, has the ground temperatures for many locations around the world.

Figure 9 – Approximate Ground Water Temperatures in the USA[7]



[7] W.D. Collins, *Temperature Of Water Available For Industrial Une in the United States*, U.S. Geological Survey Paper 520-Fl, Washington, D.C. 1925

Figure 10 – Shallow Ground Temperature Variation with Season[8]



The graph shows the variation from undisturbed ground temperature for various depths. For instance, horizontal systems usually stay within 5 ft. of the surface, which can swing by as much as 20°F from summer to winter.

Annual Energy Load and Balance

Key issues with Geothermal systems are the annual energy load and balance. If the building rejects more heat into the ground than it removes, then the borehole field average temperature will climb over time. Even if the heating and cooling loads are balanced, the amount of the energy rejected will affect the monthly ground temperature.

How fast and how much the temperature changes will depend on building usage, borehole spacing and ground water movement. Close borehole spacing will restrict the ability of the borehole to dissipate heat. On the other hand, good ground water movement will help carry away heat. If the building uses more heat then it rejects, the reverse will be true.

Monthly Effects and Equivalent Full Load Hours

The amount of energy transferred to or from the field will affect the ground temperature and the future performance of the field. This effect is generally considered on a monthly basis. A key factor is building use. Consider a school and a hospital, both with a 200-ton design load. Even though they have the same number of heat pump tons, the hospital operates around-the-clock and moves much more energy to and from the field than the school.

Most loop sizing software uses Equivalent Full Load Hours (EFLH) for heating and cooling to estimate the energy transfer effect. Equivalent full load hours are the annual heating and cooling loads divided by the installed capacity. For the hospital and school example given above, even though the installed capacity would be the same, the annual loads for the hospital will be much higher and the equivalent full load hours will be higher.

Estimating the equivalent full load hours requires some judgment and understanding of how the building is used. ***Appendix 4 – Equivalent Full Load Hours***, page 39, provides Equivalent Full Load Hours for various cities and building types based on constant temperature setpoints. The following will provide the designer with some guidance on factors that affect Equivalent Full Load Hours.[9]

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[8] Copyright 1997, American Society Of Heating, Air-conditioning and Refrigeration Engineers Inc., www.ashrae.org. Reprinted by permission from Ground-Source Heat Pump Systems: Design of Geothermal Systems for Commercial and Institutional Buildings
[9] Carlson, Steven W., Jeff W. Thornton. *Development of Equivalent Full Load Heating and Cooling Hours For GCHPs.* RP-1120. ASHRAE. Atlanta, Ga. 2002.

- **Occupancy Hours.** The amount the building is used has the greatest effect on EFLH. EFLHs can increase 95 to 120% with a tripling in operating hours.
- **Internal Gains.** Increasing the internal gains will increase the EFLH, but not as drastically as usage. Doubling the internal gains can result in a 15% to 30% increase in EFLHs.
- **Ventilation Rates.** Changing the ventilation rate in a building proportionally changes both the installed equipment capacity and the annual loads. As a result, EFLHs do not change significantly with changes in ventilation rates.
- **Setback/Setup Control.** Where night setback is used, the EFLHs are reduced by about 20%. Where night setup is used, the EFLHs are reduced by about 5%.

The above information can be used to estimate the EFLHs for use with Loop sizing software. More accurate EFLHs can be calculated using annual energy analysis software that provides annual cooling and heating loads based on building location, use, internal gains, etc. McQuay's Energy Analyzer™ can provide the annual energy balance for most buildings to quickly assist designers.

Long Term Effects

An understanding of the annual energy balance is necessary to understand the long-term effect on the bore hole field. A quick rule of thumb is to assume a 1°F to 5°F temperature rise over a 10-year period. **Table 6** provides another method based on equivalent full load hours. For warm climates where the loop is expected to handle almost continual cooling, the ground temperature can rise over 10°F, even with the bore holes widely spaced. These values are worst case scenarios. Ground water will most likely reduce the impact.

Occupancy Use vs. EFLHs Example

Occupancy	Heating (EFLH)	Cooling (EFLH)	Heating Load (MMBtu/yr)	Cooling Load (MMBtu/yr)
Chicago				
8 am to 3 pm School year (9 mo.)	461	501	559	607
8 am to 3 pm year round	461	574	599	695
8 am to 10 pm	452	831	548	1,007
24/7	315	1,233	382	1,494
Atlanta				
8 am to 3 pm School year (9 mo.)	190	811	233	992
8 am to 3 pm year round	190	881	233	1,081
8 am to 10 pm	183	1,308	224	1,601
24/7	87	1.943	106	2,379

The table above shows a model school located in Chicago (Winter load dominant) and Atlanta (Summer load dominant). Increasing the occupancy to around-the-clock use more than doubles the EFLHs for cooling. The heating EFLH declined since the internal heat can be used. While the design capacity remained unchanged, changing to around-the-clock use increased the field pipe length by 33%.

Reviewing the changes in EFLHs demonstrates several concepts regarding geothermal design.

- Building design loads are not enough. How the building is used is also very important. This is not generally an issue with other HVAC designs.
- Even northern locations have a net energy imbalance that will alter the long term average ground temperature.
- Rules of thumb such as "180ft/ton" must be very carefully applied.

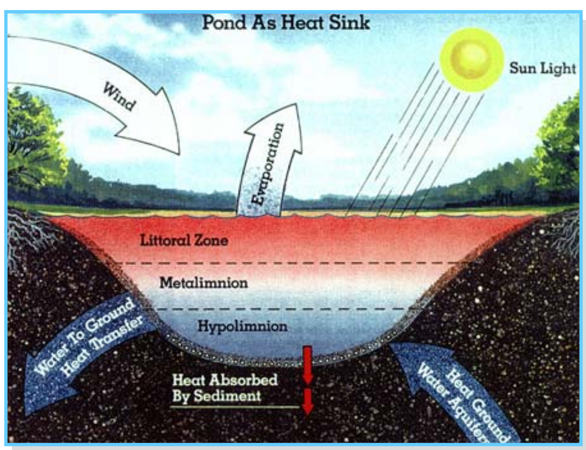
Table 6 – Long Term Temperature Change in Ground Field Temperature for a 10 By 10 Vertical Ground Loop with a 100 Ton Load[10]

Eqv. Full-Load Hrs. Heating Cooling	Bore Separation (ft)	Ground Temp. (t_g) & Entering Water Temps. (Htg. & Clg.)					
		t_g = 50°F (EWT = 35/80)		t_g = 60°F (EWT = 45/85)		t_g = 70°F (EWT = 60/95)	
		kg = 1.0	kg = 1.5	kg = 1.0	*kg = 1.5*	kg = 1.0	kg = 1.5
		Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)	Δ t_g (ft/ton)
1500 500	15	—4.4°F (318)	—4.4°F (248)	-	-	-	-
	20	—2.3°F (276)	—2.3°F (216)	-	-	-	-
	25	—1.2°F (258)	—1.2°F (202)	-	-	-	-
1000 1000	10	12.9°F(318)	11.8°F(245)	NR	11.8°F(313)	-	-
	15	5.4°F(237)	4.3°F(186)	4.7°F(245)	*4.7°F (225)*	-	-
	20	3.4°F(220)	1.9°F(172)	2.5°F(263)	2.4°F(206)	-	-
500 1500	15	15.1°F(379)	15.1°F(294)	NR	12.8°F(345)	NR	NR
	20	7.8°F (277)	8.0°F (216)	6.7°F (326)	6.7°F (254)	6.7°F (336)	6.7°F (259)
	25	4.1°F(224)	4.3°F(190)	3.5°F(287)	3.5°F(224)	3.5°F(293)	3.5°F(229)
0 2000	15	-	-	NR	NR	NR	NR
	20	-	-	10.3°F (406)	10.4°F (316)	10.4°F (4L4)	10.5°F (322)
	25	-	-	5.4°F (325)	5.5°F (252)	5.4°F (332)	5.5°F (257)

Correction Factors for Other Grid Patterns			
1 x l0 Grid	2 x 10 Grid	5 x 5 Grid	20 x 20 Grid
C_f=0.36	C_f=0.45	C_f=0.75	C_f= 1.14

Surface Water Fundamentals

Figure 11 – Pond Loop Summer Mode[11]



Surface water or pond systems use different heat transfer mechanisms than vertical and horizontal loop systems. Ponds gain heat from solar radiation, convection from air (when the air is warmer than the water) and ground conduction. The ground conduction is dominant in winter, particularly with frozen lakes.

Cooling is mostly accomplished by evaporation at the surface with some radiant and convective heat transfer. Evaporation is dependent on the surface temperature of the water, the wind speed and the ambient wet bulb. At night, radiant heat transfer to a cool dark sky can provide significant cooling. For instance, up to 50 Btu/ft² of cooling will occur from a lake that is 25°F cooler than the sky on a clear night.

[10] Copyright 1997, American Society Of Heating, Air-conditioning and Refrigeration Engineers Inc., www.ashrae.org. Reprinted by permission from Ground-Source Heat pump Heat pump Systems: Design of Geothermal Systems for Commercial and Institutional Buildings
[11] Courtesy of Loop Group, Fort Wayne, IN

The temperature gradient in ponds causes stratification both in summer and winter. Water becomes more dense as it cools until it reaches its highest density at 39.2°F.

Figure 12 - Pond Loop – Winter Mode[12]

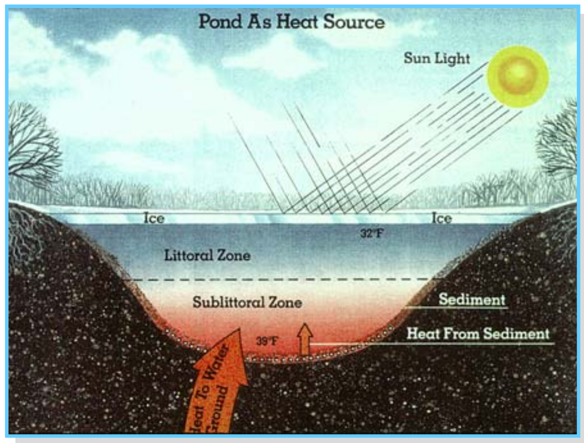
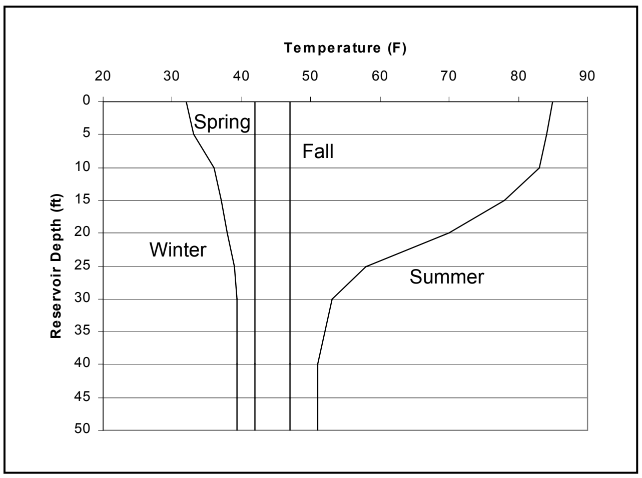


Figure 13 shows the ideal temperature vs. pond depth for four seasons. Reviewing the summer curve, the thermocline can be seen between 10 and 30 ft with colder water at the bottom. In winter, the surface water is coldest. The bottom of a deep pond is 5°F to 10°F warmer.

The ideal temperatures shown in Figure 13 do not always occur. This is due to high rates of inflow/outflow from the pond, insufficient depth for stratification, fluctuations in water level, wind, etc. The best data can be obtained by thermal survey of the pond, or a nearby pond.

Figure 13 – Pond Depth vs. Temperature[13]



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[12] Courtesy of Loop Group, Fort Wayne, IN.

[13] Copyright 1997, American Society Of Heating, Air-conditioning and Refrigeration Engineers Inc., www.ashrae.org. Reprinted by permission from Ground-Source Heat pump Heat pump Systems: Design of Geothermal Systems for Commercial and Institutional Buildings

Design Considerations

The designer must perform their normal tasks, such as zone-by-zone load analysis. In addition, the designer must also specify the geothermal type, total bore length, minimum separation distance, pipe diameter, U-bend type, operating parameters and antifreeze properties. This section will provide the designer with some detail on how to solve these issues.

Equipment and Equipment Rating

Figure 14 – McQuay Enfinity™ Geothermal Heat Pump With R-410a Refrigerant

Geothermal water source heat pumps are slightly different than Boiler/Tower heat pumps. The wider fluid operating range generally requires additional insulation of internal co-axial coil, thermal expansion (TX) valves and heat exchangers optimized for geothermal operating conditions. A geothermal heat pump can be safely operated in a Boiler/Tower system, but the reverse is not generally true.

It is important that the designer select equipment can operate at the required operating conditions for the specific geothermal project.

ARI and ISO

In the past there were three Standards provided by ARI (Air-conditioning and Refrigeration Institute) for heat pumps. Recently, ISO and ARI produced a joint Standard. The new standard also includes the fan work and the fluid pressure drop through the heat exchanger in the unit efficiency calculations. It is important that the designer specify which standard is being used as the same heat pump will yield different performance. It is highly recommended that the designer use the new ISO standard because it is the standard used to certify equipment and it provides a more thorough estimate of energy consumption.

☺*Tip: The ISO rating conditions for heat pumps do not necessarily represent the actual operating conditions. It is not necessarily a good idea to design the loop on ISO rating conditions.*

Table 7 – ARI and ISO Test Conditions

Standard	System	Cooling Rating Point (°F)	Heating Rating Point (°F)
ARI 320-93	Boiler/Tower	85	70
ARI 325-93	Ground Water Open Loop	70	50
ARI 330-93	Geothermal Closed Loop	77	32
ISO 13256-1	Boiler/Tower	86	68
	Ground Water Open Loop	59	50
	Geothermal Closed Loop	77	32

Note that the rating conditions do not represent the ***actual*** conditions a heat pump will operate under. This is particularly true for geothermal applications. It is very important that the designer realize that the ISO rating conditions are not necessarily good design conditions.

Loop Flow Rates and Temperatures

Table 8 – Flow Rates vs. Temperature Range

System Flow US gpm/ton	Temperature Range in Cooling (°F)	Temperature Range in Heating (°F)
3.0	10	6
2.5	13	7-8
2.0	15	9

Heat pumps operating in cooling reject the heat collected from the space and another 25% of the heat from the compressor. For this reason, loop flow is more like chiller condenser flow than chilled water flow. Most geothermal systems are designed with 3.0 US gpm flow rates. Lower flow rates will reduce the pump and piping size, but they will also de-rate the performance of the heat pump.

> ☺ *Tip: Most geothermal loop designs are based on 3.0 US gpm.*

In heating, the heat absorbed from the loop is added to the compressor heat to meet the space requirements. Hence the temperature range is smaller. It is important to note that if 3.0 US gpm is used as a design flow rate and all of the heat pumps are in heating, the loop temperature will drop by 6°F. If only water is used, then the supply water temperature must not drop below 42°F to avoid freezing. If temperatures below 42°F are likely, then antifreeze should be added. Adding antifreeze may change the design flow rate requirement. See ***Fluid Properties,*** page 12.

Constant vs. Variable Flow Systems

For water source heat pumps, the flow rate is based on the *connected* tonnage. For constant flow systems, this means a high flow rate is required to operate every hour of the year. Pump work is significant. Variable flow rate systems will vary the flow based on the actual load at any given time. This can cut the pump work by as much as two thirds. While downsizing the pumps and piping system to the design load flow rate is a good idea in chilled water systems (resulting in large capital savings), this is not recommended for heat pump systems. There are periods where all the heat pumps could actually be operating at the same time (morning warm-up, for example). Designing the heat pump loop on the design load flow rate would result in many heat pumps being short of flow during these periods and many would lock out. ASHRAE Standard 90.1-2001 requires variable flow for systems larger than 10 pump horsepower (Refer to ***ASHRAE Std 90.1-2001***, page 24).

Variable flow systems require two-way isolating valves at each heat pump that shut off the flow when the compressor is not running. These valves can be supplied with the heat pump, along with the controls to operate them. Since the system flow is variable, the pump must be able to modulate. Variable Frequency Drives (VFDs) are the most common method. A bypass that maintains the minimum flow rate at 33% of design is recommended. There is little pump horsepower savings below 33% (20 Hz), and the lower frequencies tend to cause undue wear on the motor and VFD.

Table 9 – Minimum Flowrate In Pipe

Pipe Size (in.)	Min Flowrate (US gpm)	Pipe Size (in.)	Min Flowrate (US gpm)
¾	4	1 ½	12
1	6	2	18
1 ¼	9	3	40

As the flow is reduced, the loop tube velocities may drop into the laminar region. This is acceptable since the plastic pipe thermal resistance is dominant. The flow only needs be non-laminar at design conditions. The oversized loop for part load conditions will offset the reduced heat transfer process. Table 9 shows the minimum flow rate in SDR 11 pipe for water to achieve 2 fps. This should provide non-laminar performance.

Design Fluid Supply Temperature

> ☺ *Tip: A good starting point for loop design temperature is that the supply fluid temperature should be 20°F to 30°F warmer than the undisturbed ground temperature for cooling and 10°F to 20°F colder for heating.*

Selecting the design inlet water temperature is an iterative process. The key is to find the balance between the supply water temperature (which improves heat pump performance as it is lowered) and ground loop size (which becomes larger and more costly as the supply water temperature is decreased). Raising the temperature will have the opposite effect. A good starting point is the supply fluid temperature should be 20°F to 30°F warmer than the undisturbed ground temperature for cooling and 10°F to 20°F colder for heating. Looping sizing software can then be used to calculate the required loop size and a balance between capital cost and operating performance found.

Design Load Analysis

Calculating the design (peak, block) cooling and heating loads is accomplished in the same manner as for any other building. Heat pumps are a decentralized system so the installed capacity is based on the *connected* load rather than the *design* load. It is not possible to move heat pumps from the East side of the building to the West side as the sun moves around! Dividing the design load by the connected load will yield the diversity, which can be 80 percent or more. The loop will respond to the *design* load. If the designer only uses the connected load when designing the loop, then the loop could be 25% larger than necessary. Since the ground loop is a major cost, proper load calculations that take into account diversity are warranted.

Safety factors should also be carefully applied as well. Oversizing the heat pumps is one thing. Oversizing the design flow rate and load will increase the piping, pumps and the ground loop – all of which result in a detrimental impact on the capital cost of the project.

Rules of Thumb

A rule of thumb is derived from a specific type of building in a given location. They are very popular in residential applications where there is no diversity (i.e. one heat pump in a house) and they tend to be based on connected load. While it is quite common in geothermal projects to talk about "bore hole feet per ton," this and other rules of thumb should be carefully weighed with a clear understanding about connected capacity vs. design capacity when applying them to commercial design.

Piping Details

The piping within the building for a Geothermal system is the same as for a Boiler/Tower system with the exception that the piping will need to be insulated if the minimum temperature is expected to be 50°F or less. Refer to McQuay's Catalog 330-1, ***Water Source Heat Pump Design Manual*** for more details on building piping design.

> ☺ *Tip: Only use HDPE piping with thermal fused joints for ground loops. SDR 17 is rated for 100 PSI, SDR 11 is rated for 160 PSI and SDR 9 is rated for 200 PSI.*

Ground loops use high-density polyethylene piping (HDPE) that is thermal fused. This is the same piping used by the gas utilities for natural gas lines. The ASTM number is 3408. More specific standards for ground loops are available from the International Ground Source Heat Pump Association (IGSPHA). These are 345434C, 345534C or 355434C. Driscoplex™ 5300 series Climateguard is a common brand name for HDPE.

Table 10 – HDPE Pressure vs. Temperature Rating[14]

Temperature	Pressure Rating (PSI)	
(°F)	SDR 11	SDR 9
73	160	200
80	151	189
90	138	173
100	126	157
110	114	142
120	102	128
130	91	114
140	80	100

Figure 15 – HDPE Pipe With Thermal Fused U-Bend[15]

HDPE piping uses Standard Dimension Ratio (SDR) for pipe sizing rather than the traditional Schedule sizes. Thermally fused piping must be SODR, which is based on the outside diameter. SIDR piping is based on the inside diameter and is meant for use with barb-type connections and a hose clamp.

An advantage of SDR ratings is the pressure rating is consistent, regardless of pipe diameter. For instance, SDR 17 is generally rated at 100 PSI for all diameters. SDR 11 is rated at 160 PSI and SDR 9 is rated at 200 PSI.

Appendix 2 – Pipe Properties, on page 37 provides pressure loss tables for various SDR piping and fittings. Table 11 provides maximum flow rates for water based on 4 ft. WPD per 100-ft. pipe.

Table 11 – Maximum Recommended Water Flow Rates (US gpm)[16]

Nominal Dia. (in.)	SDR 11 HDPE	SDR 17 HDPE	Sched 40 Steel	Sched 80 Plastic	Copper Type L
¾	4.5	-	4	3	3.5
1	8	-	7	6	7
1 ¼	15	-	15	13	13
1 ½	22	-	23	21	20
2	40	-	45	40	44
3	110	140	130	125	130
4	220	300	260	250	260
6	600	750	800	750	800
8	1200	1500	1600	1500	-
10	2200	2600	3000	-	-
12	3500	4200	4600	-	-

Based on ASHRAE recommended head loss of 4 ft water per 100 ft pipe
Multipliers for antifreeze mixtures:
20% propylene glycol = 0.85
20% methanol = 0.90

[14] Driscoplex™ 5300 Climate Guard Systems, Bulletin PP 650, CP Chem. Plano Texas.
[15] Performance Pipe CP Chem. Plano Texas
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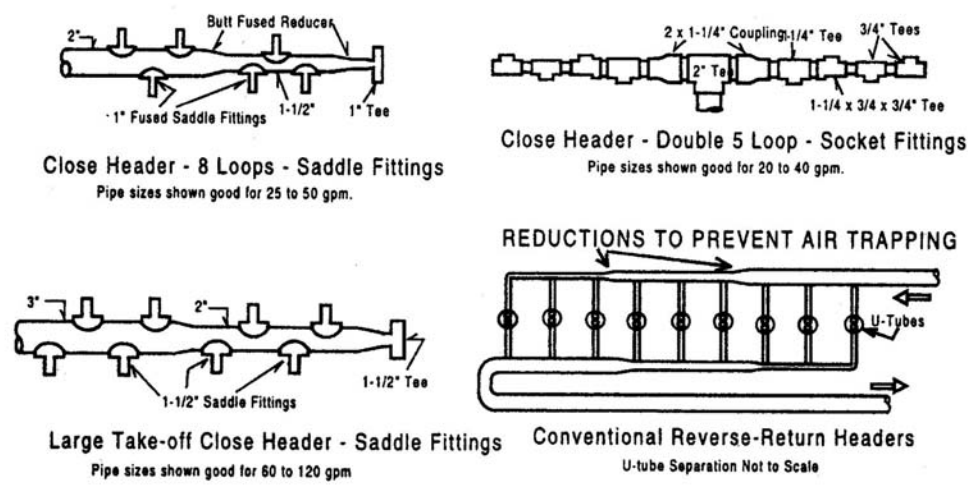
Reverse vs. Direct Return Piping

Reverse return piping is inherently self-balancing. However, it adds another leg and cost. The designer should strive to achieve a piping system that will balance to within 15% of the design flows without the use of balancing valves. If less than 30% of the ground loop head loss occurs in the longest run, direct return piping should suffice. If the head loss is greater, then reverse return piping is recommended.

Header Design

For small projects, the supply and return runouts for each loop can be brought directly to the pump room within the building. For projects over 20 tons, arranging the loops into subgroups and providing each subgroup with it's own header will be easier to manage. The subgroup headers can be fed from the pump room and each header should have its own butterfly-type isolating valve. This will also assist with flushing (See ***System Flushing,*** page 23).

Figure 16 – Header Configurations[17]



An alternative to bringing each subheader back to the pump room (which involves multiple penetrations) is that they can be fed from a vault installed in the bore hole field. A single header can then be brought back to the pump room. A vault makes sense when there are a lot of subheaders or the return distance is over 100 feet.

Another approach is to section the building and fields into smaller groups. For instance, have the East side on the building served by a ground loop on the East side. A dedicated mechanical room would need to be provided. While requiring more mechanical rooms and pumps, there are several advantages:

- Headers can be brought to the closest mechanical room, reducing pipe runs.
- Parts of the building operating on different schedules can be separated. Spaces with longer operating hours can have dedicated pumps that will not penalize the rest of the building.
- There is built-in redundancy to the system.

To assist in making the system self-balancing, the designer should reduce the headers to even the pressure drops through the loops.

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Mechanical Room Layout

Figure 17 – Typical Mechanical Room Layout[18]

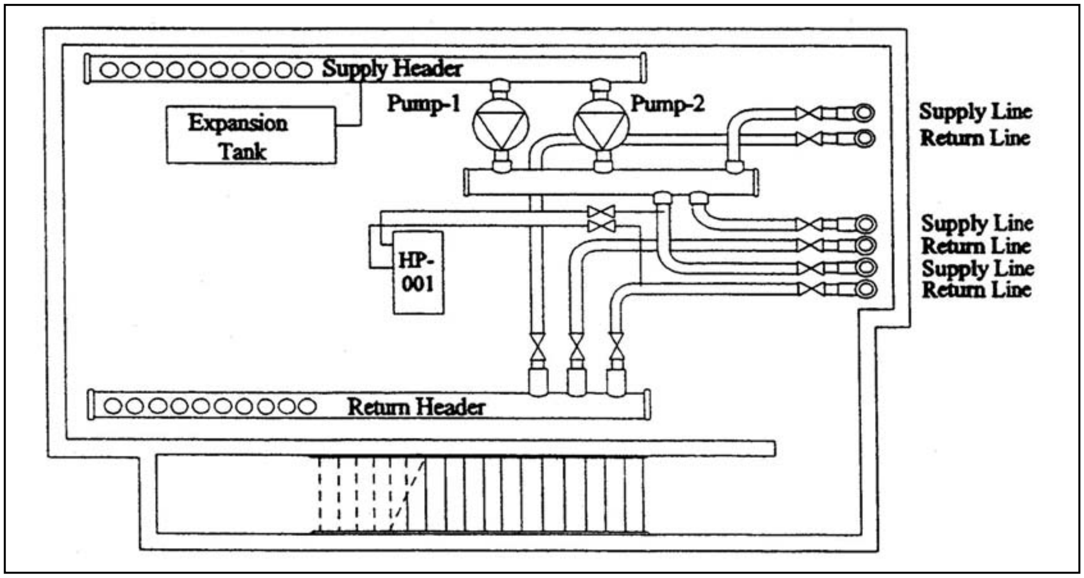

Figure 17 shows a plan view of a mechanical room with three headers. The Supply and Return headers are located where the field loops are attached. Individual loops would be isolated here. The third header allows multiple loops within the building to serve the heat pumps.

System Flushing

Removing all the air from a ground loop is more involved than with other piping systems. In most cases, additional pumps are required to get the necessary velocity to clear the pipes. Taps should be added to allow the contractor to hook up temporary pumps for flushing. The contractor can only do 10 to 20 tons of loop at a time, so valves are required to isolate loop sections. Even with small loops, it will be difficult to remove all the air. Air separators should be installed to help remove the remaining air.

Pumping Design

By their nature, geothermal projects are meant to be energy efficient. To accomplish this, the pumping system must be designed properly. Without flow, no heat pump can operate. It is typical to have a 100% redundant pump for backup. Alternatively, three pumps can be used, each sized for 50% of the design flow. At least two pumps will be required to meet the design flow. For variable flow systems, the pumps should be controlled with Variable Frequency Drives (VFDs).

Check valves are required on each circulating pump. Triple duty valves are common for flow control, but the pump impellers should be trimmed rather than relying on the valve to balance flow.

The following recommendations are given to help the designer:

- ❑ Limit design flowrate to 3.0 US gpm/ton of the design load
- ❑ Select pipe sizes at 4 ft WPD/100 ft. Try to minimize fitting losses.
- ❑ Select pumps within 5% of maximum efficiency. During commissioning, have the pump impellers trimmed, if necessary, rather than using a balancing valve to reduce flow.

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- Minimize the use of antifreeze.
- Consider multiple ground loops serving various parts of the building, particularly if the building use is different in each area.

The potentially cold fluid can cause condensation to form on the pump and motor windings. The pump should be designed to handle the minimum expected loop temperature.

Water Make-up

A backflow preventer is required by most local codes. This is particularly true if antifreeze is used. An alarm that senses abnormal make-up is recommended in case there is a leak in the field. A routine check of the antifreeze is recommended in the Fall (prior to the Winter season) to make sure water make-up has not diluted the concentration.

Pump Control

Constant flow systems require the design flow at all times, even if only one heat pump is operating. If constant flow systems are being used, then a control system that recognizes when no heat pumps are operating and can shut down the circulating pumps is recommended. A DDC system can handle this. A less expensive method is to use the pump restart feature in the Mark VI board of McQuay heat pumps. Refer to ***McQuay Heat Pump Product Catalogs*** for details.

Variable flow systems will require a pressure transducer to measure the pressure drop across the loop. This signal can be used to control the speed of the pumps and maintain the required system pressure. If the minimum pump speed is reached and the pressure begins to climb, the bypass valve should open and maintain minimum flow.

A method to control the redundant pumps is also required. Should a pump fail, the spare pump must be started immediately or all of the heat pumps serviced by the loop will trip on a safety.

ASHRAE Std 90.1-2001

ASHRAE 90.1-2001 requires the following for pumps:

- The hydronic system be proportionally balanced in a manner that first minimizes throttling losses and then trims the impeller or adjusts the speed to meet the design flow conditions (6.2.5.3.3)

Exceptions include:

  - Pumps with motors less than 10 hp.
  - When throttling results in no greater than 5% of nameplate horsepower or 3 hp, whichever is less.

- Systems with a total pump nameplate horsepower exceeding 10 hp shall be variable flow and able to modulate down to 50%. (6.3.4)
- Individual pumps with over 100-head and a 50-hp motor shall be able to operate at 50% flow with 30% power.
- The differential pressure shall be measured at or near the furthest coil or the coil requiring the greatest pressure differential.

  Exceptions include:

  - Where minimum flow interferes with proper operation of the equipment (i.e., the chiller) and the total pump horsepower is less than 75.
  - Systems with no more than 3 control valves.

- Each heat pump shall have its own two-way isolating valve to shut off flow when the compressor is not operating. (6.3.4.4)

Estimating Loop Fluid Volume

Estimating the loop fluid volume is important for sizing the expansion tank and calculating the amount of antifreeze. Table 12 shows the volume per 100 ft. of pipe for various types and diameters.

Table 12 – Fluid Volume Per 100 ft Pipe

Pipe Type	Nominal Size (in)	ID (in)	Volume (US gpm/100 ft)
SDR 17	2	2.09	17.8
	3	3.09	39.0
	4	3.98	64.5
SDR 11	¾	0.86	3.0
	1	1.08	4.7
	1 ¼	1.36	7.5
	1 ½	1.55	9.8
	2	1.94	15.4
	3	2.86	33.4
	4	3.69	55.4
Schedule 40	¾	0.82	2.8
	1	1.05	4.5
	1 ¼	1.38	7.8
	1 ½	1.61	10.6
	2	2.07	17.4
	3	3.07	38.4
	4	4.03	66.1

Estimating Pipe Pressure

Elevation changes, particularly in vertical loop systems, can lead to high hydrostatic pressures. Designing a system with 200 ft deep bore holes is equivalent to working on a 20 story project! The maximum pressure in the pipe is equal to:

$$P_{max} = p_o + h \cdot \rho/144 + 0.5 \cdot p_h$$

Where

P_{max} is the maximum pressure (psi)

p_o is the static pressure (psi)

h is the maximum height difference in the fluid loop (ft)

ρ is the fluid specific weight (density times acceleration due to gravity) (lb/ft^3)

p_h is the pump head (psi)

Pipe Pressure Calculation Example
Consider a 4-story building with vertical bore hole field drilled to 200 feet. The pump head is 80 feet and the fluid is 20% ethanol. The system static pressure is 10 PSI. What pressure rating of pipe should be used?

Solution
A 20% ethanol solution has a specific gravity of 61 lb/ft^3

The pump head is 80 feet, which converts to (80 ft) x (61 lb/ft^3)/(144) = 33.9 PSI

The maximum height difference is assumed to be from the top of the building to the bottom of the bore hole. In this case, 4 stories x 12 ft + 200 ft bore hole = 248 ft.

The maximum pressure is:
= 10 PSI + (248 ft) x (61 lb/ft^3)/144 + (0.5) x (33.9 PSI)
= 132 PSI

Therefore SDR 17 (100 PSI rating) is not acceptable. However, SDR 11 (160 PSI rating) is acceptable.

Ground Testing

Figure 18 – Field Testing Apparatus[19]

Ground testing provides the designer with accurate information on the thermal conductivity. With this information, the loop design can be optimized (in most cases) and the length of piping reduced. If the bidding contractors will test bore data and drilling conditions on the site, this will remove some of the uncertainty and they may provide a price with less of a hedge in it.

The tests are generally conducted by drilling a bore hole and adding a loop. Hot water from a portable electric heater is circulated. A data log is run over 48 hours and the energy absorbed by the ground is measured. From this, the conductivity and diffusivity can be calculated.

Ground tests can cost $2000 per bore hole depending on site conditions. They make sense for projects over 50 tons, or if the site conditions are not well understood.

☺ *Tip: Ground tests cost about $2000 per borehole. They should be done for projects over 50 tons or if the site conditions are not well understood.*

[19] Performance Pipe C.P Chem., Plano TX.

Horizontal Loop Design

Figure 19 – Horizontal Loop

Horizontal loops are installed in trenches 3 to 5 feet deep. Deeper trenches may require sidewall supports, which would increase the installation cost. Several circuits can be installed, one on top of the other, in the same trench.

The shallow depths place the loops where the undisturbed ground temperature would naturally change with the seasons. This lowers the efficiency and increases the total pipe length required. The typical loop temperature operating range is 35°F to 100°F.

Horizontal loops are generally easier to install than either vertical or surface water systems.

Horizontal loops require large areas, typically 2500 ft² per ton. The trenches are about 150 to 220 ft per ton. The installed cost runs around \$600 to \$800 per ton.

Figure 20 – Installing Horizontal Loop[20]

The large area requirement makes horizontal loops more applicable to smaller projects. or projects with large land areas available. Running the loop under parking areas (particularly paved areas) is not recommended.

[20] Courtesy of Loop Group, Fort Wayne, Indiana

Vertical Loop Design

Figure 21 – Vertical Loop

Vertical loops are installed in bore holes 200 to 400 feet deep. The holes are typically backfilled with grout (see ***Backfill and Grouts***, page 9).

Each hole requires about 250 ft² of surface area. Vertical systems use much less land than horizontal systems. The range is 180 to 250 ft of borehole per ton. The cost is about $900 to $1300 per design ton.

The undisturbed ground temperatures at the depth vertical systems operate remains constant throughout the year. Typical loop temperature operating range is 35°F to 90°F in Northern climates. In Southern climates, the loop temperatures can climb to 100°F.

Figure 22 – Installing Pipe and Backfilling a Vertical Hole

Drilling Process

Figure 22 shows a drilling rig boring a hole. Once the hole is drilled the HDPE pipe is lowered into the hole along with the grout pipe. As the grout pipe is removed, the hole is backfilled.

Bore hole Layout

Bore hole layout is a key component of a good geothermal design. If the bore holes are placed too close together, the heat will not dissipate and the ground temperature will rise over time (The opposite will happen if the system is an annual net heat consumer). A second risk is that bore holes will run into each other. It only takes a small angle over the large depths involved to cause two holes to run into each other.

Approximately 25 foot centers are required to provide enough core volume for the heat to dissipate from a typical hole without having a long term effect on the average ground temperature. Most economical systems are based on 15 to 20 foot centers. The actual spacing should be found using computer program.

Bore holes on the perimeter of the field can dissipate heat better than those in the core area. Designs that increase the number of holes on the perimeter (long narrow layouts) are more effective. Bore holes can be under a paved parking lot.

Figure 23 – Typical Vertical Loop Piping Arrangement[21]

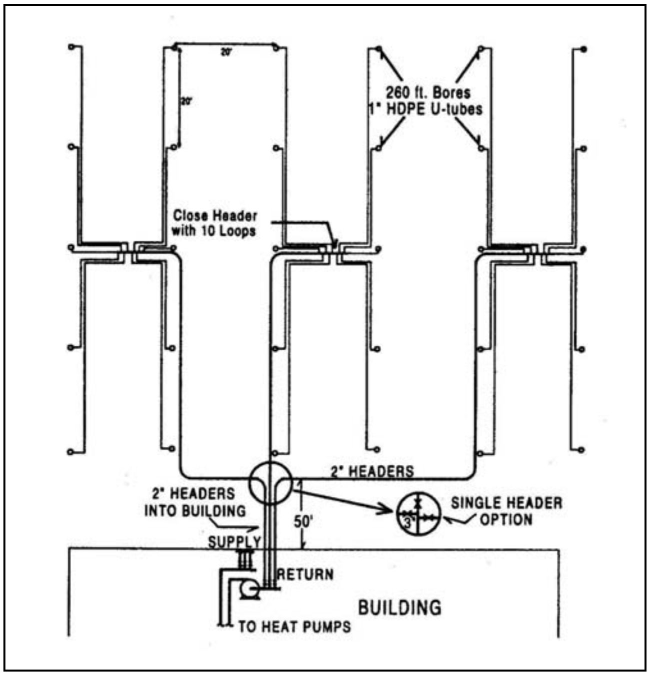


Figure 23 shows a typical reverse return vertical loop layout.

Information for sizing piping is covered in ***Piping Details***, page 20 and **Appendix 2 – Pipe Properties**, page 37. For initial sizing and evaluation, Table 13 lists guidelines for selecting vertical loop pipe size. Most return headers are 2 inch. If subheaders or vaults are used, then the pipe should be sized at 4 ft WPD per 100 ft or less.

Table 13 – Guidelines for Vertical Loop Pipe Sizing

Range Of Bore Length per Parallel Circuit			
U Tube Dia (in)	**Desired Pumping Efficiency**		
	High	Med	Low
¾	100-200 ft	Up to 250 ft	Over 250 ft
1	150-300 ft	Up to 350 ft	Over 350 ft
1 ¼	250-500 ft	Up to 600 ft	Over 600 ft
1 ½	300-600 ft	Up to 1000 ft	Over 1000 ft

Software Design

Software is now readily available to size horizontal and vertical ground loops. While somewhat different in format, most require the same basic inputs from the designer.

- **Design Fluid Supply Temperatures.** For cooling try 20°F to 30°F above the undisturbed ground water temperature and 10°F to 20°F colder for heating. ***Do not use the ISO rating conditions for heat pumps.***
- **Ground Temperature.** This is the undisturbed ground temperature that can be found in ***Appendix 1 – Ground Temperatures*** (Page 36) for many cities. Horizontal loops will require data to account for seasonal ground temperature changes near the surface. In some instances, ambient air conditions are used to estimate ground temperature changes.
- **System Flow Rate.** ton / gpm.
- **Fluid Properties.** If antifreeze is required, the properties need to be entered. Do not unnecessarily use too much antifreeze.

[21] Copywrite 1997, Americal Society of Heating, Air-Conditioning and Refrigeration Enginners Inc., www.ashrae.org. Reprinted by permission from *Ground-Source Heat Pump Systems: Design of Geotermal Systems for Commercial and Institutional Buildings*

- **Soil Properties.** Both conductivity and thermal diffusivity are required. These should come from either a site test or an accurate estimate.
- **Pipe Properties.** These include pipe thermal resistance, diameter, flow type (turbulent vs. Laminar) number of pipes per hole, placement in hole, backfill properties, etc.
- **Field Arrangement.** Number of rows across and down, separation distance, number of bores per parallel circuit, etc.
- **Design Day Load Profiles.** Design programs require both a design cooling and design heating day load profile. It may be 24-hour or grouped into smaller (4 hour) periods. In addition, the annual equivalent full load heating and cooling hours are required.

Fine Tuning the Design

The designer is challenged to strike a balance between capital cost (a large bore field) and operating performance (reduced heat pump EER due to a smaller bore hole field). The best balance may take a few iterations. Fortunately, the use of computer software to design the loops allows several iterations in a short period of time. The following is a list of possible changes to the design and their impact.

- **Increase the Design Loop Supply Temperature.** Raising the supply temperature will reduce the loop size but penalize the heat pumps. Raising the loop temperature 5°F can decrease the loop size by 10 to 15%. However, the heat pump design performance can drop 5 to 10%. The heat pumps are only penalized when the loop is at the design temperature. It is not possible to estimate the annual operating penalty associated with increasing the temperature. Energy Analyzer™ can be used to evaluate a high loop design condition.
- **Change Bore Hole Distance.** Increasing the bore hole distance will allow energy to dissipate better. It will also minimize the long term effect. This approach will only be effective if there is a large difference between annual heating and cooling loads. Bore hole centers beyond 25 feet will not provide much improvement. Reducing bore hole separation will reduce the required land but increase the thermal interference between holes. For instance, reducing the center distance from 20 to 15 feet saves over 40% in land, but it increases the pipe length by over 20%
- **Use a Hybrid System.** A hybrid system will allow the loop to be sized for the smaller of either the cooling or heating requirement. Refer to ***Hybrid Designs,*** page 33.
- **Test the Ground Conductivity.** When a test is performed, the designer can reduce the design safety factor with more confidence. In most cases (for systems over 50 tons) the test will pay for itself in reduced bore holes.
- **Test the Hydrological Conditions.** Ground water movement can help dissipate energy and reduce annual and long-term temperature changes in the ground. Allowing for minimized annual loop temperature changes can reduce the loop size by 20%.
- **Change Tube Diameter.** Larger tube diameters have better thermal performance, but they are more difficult and expensive to install.
- **Change Bore Hole Depth.** Increasing the depth will reduce the number of bore holes, but it may require larger pipes to carry the increased flow.

Surface Water Design

Figure 24 – Surface Water Loop

Surface water loops require a pond or lake. These can be natural or man made. In some locations, there are code requirements to catch and store rain water runoff on the property. In these cases, the storage pond can be the geothermal pond.

Pond depths are usually 10 to 12 feet minimum. The pond size depends on many factors (see ***Surface Water Fundamentals,*** page 16). Heating dominated loads are generally more demanding. Pond sizes can vary from 10 to 50 tons per acre.

The typical operating range for surface water systems is 35°F to 87°F. This is better than either vertical or horizontal loops, particularly in hot climates. The advantage surface water systems have in cooling is the evaporative effect of the water.

Figure 25 – Installing Pond Loop [22]

Piping Design

Piping systems are generally made up of 300 to 350 ft coils of ¾ in. HDPE pipe. Each coil will reject about 1 ton of heat to the water. To improve heat transfer, the turns of the coil are separated with spacers.

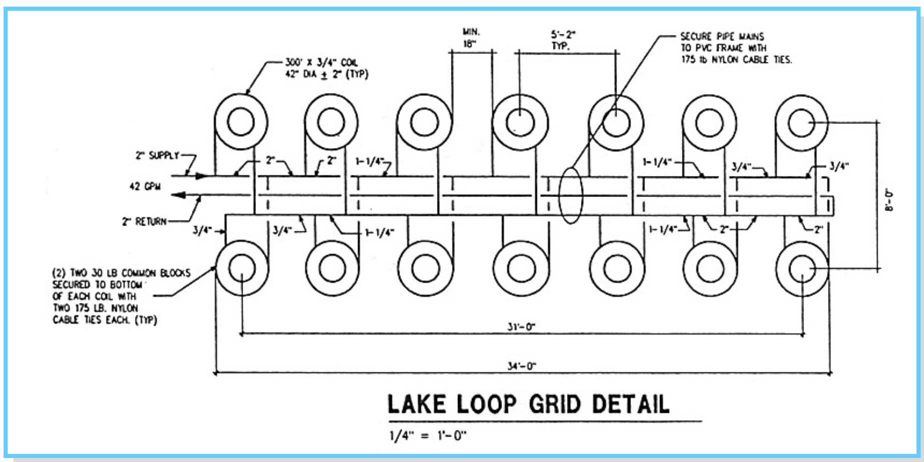
The coils are assembled in frames, either at the jobsite or remotely. They are attached to 2-inch headers and floated into the pond as shown in Figure 25. Once in place, the coils are filled with water and allowed to sink to the bottom.

Antifreeze is common even in warm climates. Pond water temperatures can reach as low as 42°F, which can lead to freezing conditions in the heating mode. Special attention should given to where the pipes leave the pond to reduce the possibility of mechanical damage and potential freezing.

[22] Courtesy of Loop Group, Fort Wayne, Indiana

Figure 26 – Coil Spacers[23]

Figure 27 – Typical Pond Loop Piping Arrangement[24]



Software Design

Software for surface water design will require the following information.

- **Design Fluid Supply Temperatures.** For cooling, try 20°F to 30°F above the undisturbed ground water temperature and 10°F to 20°F colder for heating. Do not use the ISO rating conditions for heat pumps.
- **Ground Temperature.** This is the undisturbed ground temperature and can be found in ***Appendix 1 – Ground Temperatures*** (Page 36) for many cities. Ambient air conditions may also be requested since the headers are similar to a horizontal ground loop system.
- **System Flow Rate.** Try 3 US gpm / ton.
- **Fluid Properties.** If antifreeze is required, the properties need to be entered. Do not unnecessarily use too much antifreeze.
- **Surface Water Properties.** The average summer and winter water temperatures at the depth where the bundles will be located. Also, the pond surface area and circuit depth are required.
- **Pipe Properties.** These include pipe thermal resistance, diameter, flow type (turbulent vs. Laminar), number of pipes per hole, placement in the hole, backfill properties, etc.

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[23] Courtesy of Loop Group, Fort Wayne, IN.
[24] Courtesy of Loop Group, Fort Wayne, IN.

Hybrid Designs

It is rare that the annual heating and cooling loads are equal. When the cooling load exceeds the heating load annually, the average ground temperature will climb over time until an equilibrium is reached. This will either lower the performance of the system from design conditions, or pipe length must be added to account for the long-term performance drop.

An alternative solution is to use a hybrid system. Hybrid systems consist of both a ground loop and supplementary cooling equipment – such as a closed circuit cooler. Hybrid designs come in many forms, but the goal is to balance out the annual load on the ground loop. Consider a building with a net heat addition to the loop. In other words, the loop size is dominated by the cooling load. One hybrid solution would be to size the ground loop to meet the heating load only. A closed circuit cooler handles the difference between the actual heat of rejection and the ground loop capacity. The cooler design conditions must be based on the ground loop design water temperatures and the local design wet bulb. These conditions may be different than conventional Boiler/Tower design conditions.

Ventilation System Design

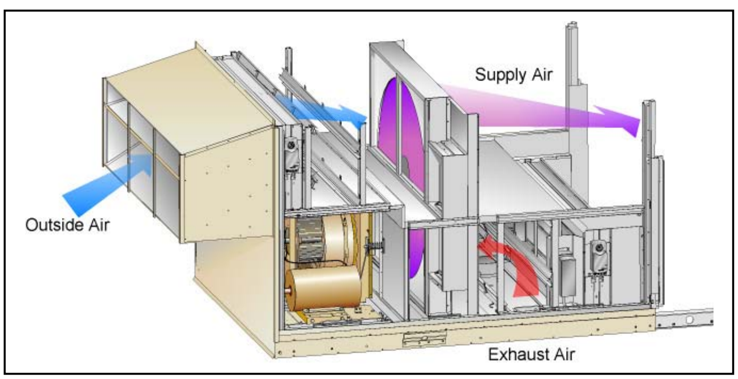
The ventilation load in a commercial building can range from 15% of an office building design load to over 30% in a school. Ventilation air represents a large part of the annual heating and cooling operating cost. How the ventilation load is handled will have a major impact on the overall operating performance.

Proper treatment of the ventilation air has a large impact on humidity control and indoor air quality. Since heat pumps are on-off devices that cycle to meet part load conditions, humidity control by the ventilation unit is critical. If the ventilation unit does not control humidity properly, humidity will enter the occupied space during periods when the heat pump is off.

Most efficient Geothermal designs include some method to minimize humidity by using electricity or natural gas to condition the ventilation air. General approaches include using energy recovery (such as enthalpy wheels) and attaching the ventilation load to the ground loop. For more information on ventilation system design, refer to McQuay Application Guide ***AG 31-004, HVAC School Design***.

Enthalpy Wheels

Figure 28 – McQuay Rooftop Unit with Enthalpy Wheel



Enthalpy wheels can transfer both sensible and latent energy. In cold weather, the enthalpy wheels can warm outdoor air into the 40°F range or better. They can also humidify the outdoor air, typically cutting the humidity load in half. In warm weather, enthalpy wheels can lower both the sensible and latent levels of the outdoor air. Typical leaving air conditions from an enthalpy wheel are around 80°F db, 67°F wb. For many climates, no further cooling is required. Any additional load can be handled by the heat pumps.

An enthalpy wheel ventilation unit alone, even with natural gas or electric heat, can provide a major improvement in the operating cost of a building. The systems are available pre-packaged (see Figure 28) and they are straightforward to design and operate. They are an excellent choice for schools.

Templifiers™

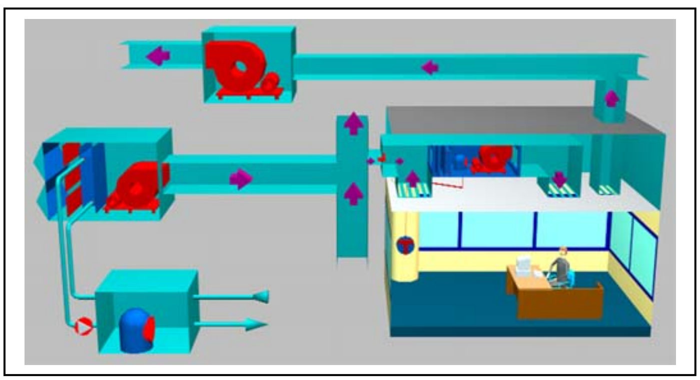
Figure 29 – McQuay Templifier™

A Templifier™ is a water-to-water heat recovery device. It can take low-grade heat in a *source* loop and use it to heat a hot water loop 70°F to 80°F warmer than the source loop. For Geothermal applications, the Templifier™ can heat a hot water loop from the ground loop. The hot water loop can be used for the ventilation load, for entrance heaters and for other heating loads that are not easily handled by a heat pump. The hot water loop can have antifreeze at concentrations appropriate to avoid freezing when used in 100% outdoor air systems.

Using a Templifier™ with an Enthalpy wheel can avoid the use of natural gas or electricity to directly heat or cool the ventilation air. A natural gas line can also be avoided. In some cases, the Templifier™ can handle the domestic hot water load as well.

Water-to-Water Heat pumps

Figure 30 – Water-to-Water Heat pump Ventilation Air Application



Water-to-water geothermal heat pumps can be used to produce either hot water or chilled water from the ground loop. The water produced by the water-to-water unit can be used to either heat or cool the ventilation air as required.

Water-to-water units avoid the use of electricity and natural gas to directly condition the ventilation air. However, compressor work is required in cooling mode, so they are not as efficient as a Templifier™/ enthalpy wheel arrangement. They are, however, generally less expensive.