A SunCam online continuing education course

Geothermal Boreholes

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Geothermal Boreholes

Geothermal or Ground Source Heating and Cooling Systems (subject to 26%, 22% in 2023 and 10% commercial Federal Tax Credits) use the earth to store and withdraw heat. During summer cooling months, heat is rejected from the building served and stored into the ground. In winter months, the process is reversed and the heat is withdrawn from the ground and placed back inside the building. Over the years, the cycle continues as the underground soil and rock act like a giant rechargeable battery, not with electricity, but with BTUs. Heat is pumped into the building when needed and pumped into the ground when not. Balanced load planning allows efficient use of the thermally conductive properties of the earth, depending on climate and building size needs.

The medium to move the heat is the ground exchanger, which is water and antifreeze circulating in buried High Density Polyethylene Pipe (HDPE) or PEX pipe. Ground source heat processes addressed in this course differ from "hot rocks" geothermal commercial electricity generating systems that are located thousands of feet deep, but both terms are used. Conventional borehole fields use the upper 800'-1000' depths only, while small commercial and residential operations generally limit pressure by using only 300'-500'deep boreholes. "Pump and dump" systems that are classified Open Loop, not Closed Loop, are not addressed here nor is Direct Exchange DX, where copper tubes with refrigerant are drilled into the ground. The International Ground Source Heat Pump Association (IGSHPA) recognizes the closed loop systems for good environmental performance and this SUNCAM course parallels the IGSHPA methods. www.igshpa.okstate.edu/index.htm

The well drilling industry for domestic potable water supply has served our nation well, back before the time of this 1901 photo. Many well drillers who have had reduced business opportunity in the current new home construction recession, are retooling to drill and grout ground source heating and cooling boreholes. Design professionals are similarly using the skills to plan out new or retrofit geothermal

systems.
For basic information on Ground Heat Exchange (GHEX) horizontal loops buried by excavator or trencher in long trenches, refer to SUNCAM course 029.

Heat pumps are simply refrigerators. The R410A refrigerant, which "boils" at room temperature, is the optimum way to move heat in and out of a building with minimal compressor electricity. Course 045 describes Ground Source Heat Pump operation inside the building. This course goes beyond to prepare the reader to take the IGSHPA Drillers or Installers accreditation workshop and become knowledgeable in small commercial and residential geothermal borehole ground exchange.

Just as drilling equipment has evolved through the years, so too have the design practices for geothermal. AutoCAD drafting programs allow accurate layout of borehole fields on a site plan.

Software programs are available to determine required depths of boreholes, separation spacing, sizing of borehole diameter, and loop pipe diameter.

The IGSHPA accredited installer understands the manual calculations that are the basis for these programs such as Geo Designer, Geo Analyst, LoopLink and WriteSoft Loop designer (www.writesoft.com).
Some are available for free from heat pump manufacturers. Some are licensed for a nominal yearly fee, and some may be purchased outright. Sample output is also shown below.

Good engineering skills and office operation are conducive to a successful geothermal design and installation practice.

Horizontal Loops are considered equal in function to vertical boreholes, but 8 out of 10 new designs are for boreholes, which take much less engineering planning up front. Proper geothermal borehole design starts with understanding the thermal conductivity of the earth and rock formations, i.e., the measure of the rate that heat flows through the material. Note from Table 1, Thermal Conductivities of Various Material at 77 °F Temperature in the Addendum, that denser materials have better or higher values of thermal conductivity. Observe also the English Units for values of Thermal Conductivity, *K*, which are not to be confused with metric data.

DATA Collection

A typical thermal conductivity value for rock is K = 1.4. Normally, dependable K ratings greater than 2.0 are not common because of uncertainty. In closed loop designs, one cannot assume that water will flow horizontally along boreholes at deep depths below the water table fluctuation zone, unless specific withdrawal is measured. In addition, very little solar heating penetrates to depths beyond 50' <u>or so</u>, where earth temperatures remain more constant.

Thermal conductivity testing is one method employed to focus on accurate K values, as discussed later. Rock identification is addressed now.

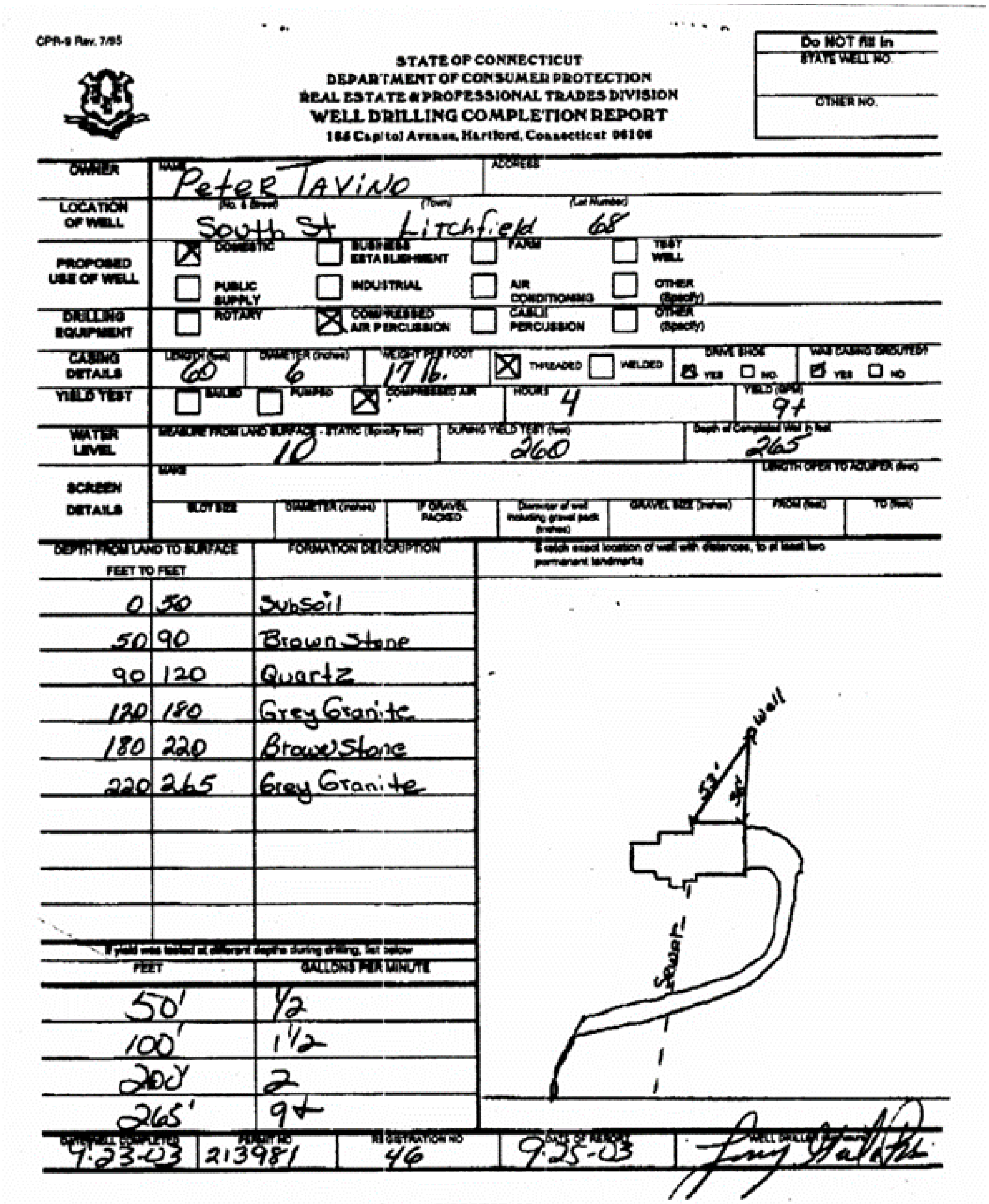
Figure 1 USGS map.

USGS maps for sale, figure 1, showing rock at the author's home, are one source of information. On-line data of rock is becoming more readily available through the USGS. Soils data is also on-line as described in course 029. Rock information is not pertinent for horizontal trenching through soils and is used only for vertical or directional borehole drilling. Sources are:

- Maps like the one above
- Drillers logs of nearby potable water wells.
- Sample test holes and possible thermal conductivity testing for big projects.

Once the rock type is known, it should be thoroughly researched on-line for information about its thermal conductivity. IGSHPA categorizes rocks by their Petrological Grouping 1 to 8. Consult the table for ranges to be used. Rock in petrologic groups 7 or 8 such as limestone marble or sandstone have higher *K* values than pumice and basalt in groups 1 and 2. Granites, Quartz, Gneiss and Schist in groups 5 and 6 have above average *K* values, where *K* = 1.4 is usually conservative. Unfortunately, rock data is not as abundant on the internet as designers would prefer. Therefore, it will be necessary to research all sources as much as possible if specific conductivity testing cost is prohibitive.

Where actual boring logs are available, such as the one in figure 2, an interpolated value for *K* (in this case 1.6 BTU/hr. ft. ^{o} F) can be determined, as follows:



OPR-9 Rev. 7/95

STATE OF CONNECTICUT
DEPARTMENT OF CONSUMER PROTECTION
REAL ESTATE & PROFESSIONAL TRADES DIVISION
WELL DRILLING COMPLETION REPORT
165 Capitol Avenue, Hartford, Connecticut 06106

Do NOT fill in
STATE WELL NO.
OTHER NO.

OWNER — NAME: Peter Tavino — ADDRESS:

LOCATION OF WELL — (No. & Street) South St — (Town) Litchfield — (Lot Number) 68

PROPOSED USE OF WELL: [X] DOMESTIC [ ] BUSINESS ESTABLISHMENT [ ] FARM [ ] TEST WELL [ ] PUBLIC SUPPLY [ ] INDUSTRIAL [ ] AIR CONDITIONING [ ] OTHER (Specify)

DRILLING EQUIPMENT: [ ] ROTARY [X] COMPRESSED AIR PERCUSSION [ ] CABLE PERCUSSION [ ] OTHER (Specify)

CASING DETAILS: LENGTH (feet) 60 — DIAMETER (inches) 6 — WEIGHT PER FOOT 17 lb. — [X] THREADED [ ] WELDED — DRIVE SHOE [X] YES [ ] NO — WAS CASING GROUTED? [X] YES [ ] NO

YIELD TEST: [ ] BAILED [ ] PUMPED [X] COMPRESSED AIR — HOURS 4 — YIELD (GPM) 9+

WATER LEVEL: MEASURE FROM LAND SURFACE - STATIC (Specify feet) 10 — DURING YIELD TEST (feet) 260 — Depth of Completed Well in feet 265

SCREEN DETAILS: MAKE — SLOT SIZE — DIAMETER (inches) — IF GRAVEL PACKED — Diameter of well including gravel pack (inches) — GRAVEL SIZE (inches) — LENGTH OPEN TO AQUIFER (feet) FROM (feet) TO (feet)

DEPTH FROM LAND TO SURFACE FEET TO FEET		FORMATION DESCRIPTION
0	50	Subsoil
50	90	Brown Stone
90	120	Quartz
120	180	Grey Granite
180	220	Brown Stone
220	265	Grey Granite

Sketch exact location of well with distances, to at least two permanent landmarks

well, 53', 38', sewer

If yield was tested at different depths during drilling, list below

FEET	GALLONS PER MINUTE
50'	1/2
100'	1 1/2
200'	2
265'	9+

DATE WELL COMPLETED 9-23-03 — PERMIT NO. 213981 — REGISTRATION NO. 46 — DATE OF REPORT 9-25-03 — WELL DRILLER [signature]

Figure 2 Example of boring log from project.

Table 2 Weighted Average Thermal Conductivity

Layer	Start	End	Thickness	K	T x K
Topsoil/Loam	0	5	5	0.52	2.6
Hardpan	5	50	45	1.44	64.8
Brown (Sand) Stone	50	90	40	1.6	64
Quartz	90	120	30	1.73	51.9
Grey Granite	120	180	60	1.7	102
Brown (Sand) Stone	180	220	40	1.6	64
Grey Granite	220	265	45	1.7	76.5
Sum		**265**			**425.8**
425.8 / 265	**= 1.607**	**= Avg. K**			

For larger projects with ample budget, soil sampling and thermal conductivity testing can enhance design. In the photographs below, a sonic drill rig takes core samples with a 6' long outer steel casing and a transparent plastic inner coax tube. A sonic drill rig can drill through soil at a particular frequency before encountering a boulder that would normally wobble under a conventional air rig. By switching to a higher frequency, the drill rig can core a 6" hole through the boulder and proceed to the soil below.

Figure 3 Demonstration of Coring Techniques with Percussion Drill, far left, and Sonic Drill, right.

Along with the inspection of cores, Thermal Conductivity Testing on one or two boreholes is recommended for any project numbering 30 or more tons. Equipment can be rented for a nominal fee to record 48hours worth of temperature data to a laptop computer. This information is then emailed to a processing company that can prepare a report and determine an accurate *K* value. Advanced Thermal Diffusivity values are not used in common borehole calculations. Diffusivity is the ratio of a rock or soil's ability to conduct heat versus its ability to store heat. More information is here: http://geoheat.oit.edu/otl/otl02-04.pdf.

The GeoCube thermal conductivity / thermal response test unit and the associated boot camp training prepare the user to perform a thermal conductivity test of a borehole. The author recommends this one day course after taking it himself. For pure electric power sources, the software plots temperature against time and uses the graphed slope to determine thermal conductivity of the formation below. Geothermal Training Institute in Maple Plains, MN offers occasional training.

The borehole to the left was tested for Thermal Conductivity of 1.73 Btu/hr ft F.

Figure 4 Boreholes in Oklahoma red clay by Track Drill, left, and the same filed with Loop Tails exposed, right.

Figure 5 New England grey granite cuttings rise to the surface.

The selected single K value is usually specified for the entire borehole and borehole field. Drillers should not drill shallower boreholes in soil that avoids higher K values in rock below, as designed. Deeper wells will not normally penetrate a deeper area with lower K values, but pressure on the loop pipe may be a concern.

GHEX BOREHOLE DESIGN

Once soils and rock contents are established, and a K factor is determined, the design of the ground exchange length can be calculated. A worksheet available to IGSHPA members has been incorporated into software programs. Behind this long formula is a simple one:

$$Length = \frac{Efficient\ Building\ BTUs\ \ x\ \ Borehole\ Thermal\ Resistance}{Temperature\ of\ Ground\ minus\ Loop\ Water}$$

Or more specifically for a single borehole:

$$Length = \frac{Hc\frac{COP-1}{COP}\ x\ \{Rb + (Rg\ x\ Fh)\}}{Tg - \{\frac{(EWT-LWT)}{2}\}}$$

Variables that must be input include:

- Heat pump heating capacity.
- COP or EER.
- Electric demand.
- Building loads.
- Heat pump run fraction time.
- Entering and Leaving Water Temperature (EWT & LWT).
- The configuration of the boreholes themselves:
    - Diameter of drill bit.
    - Size of loop pipe.
    - *K* of grout and earth.
    - Center to center spacing, etc.

Bottom line rule of thumb in moderate heating zones above the Mason Dixon line is 150’ of depth per ton in *K* = 1.4 rock. But software programs with input by knowledgeable designers should be utilized (Don’t be a “Short Looper”). Once the total Length (or Depth) for a project is known, it can be divided into multiple boreholes at convenient drilling depths such as 400’ each. Spacing at 25’ on center, if land allows, is preferable to 15’ on center where interference can occur, as the same earth space is asked to store and release heat to multiple locations. Check tables for extra borehole depths for tight spacing.

In the example shown in figure 6, a heating load of 55,000 BTU per hour (the default) can be supported by 621' of bore (two holes at 311' each) in average *K* = 1.4 BTU/hr. rock. (Rule of thumb check = 55,000/12000 = 4.58 tons = 135' per ton.) This will increase as ground load balancing (the NNAGL= Net Normalized Annual Ground Load) is computed. As an example, for 25' on center spacing, and if NNAGL = 3000, the IGSHPA chart multiplier will be 1.10 x 621 = 683' or two holes at 342'. Rate is 149' per ton. Spacing at 15' on center, where less land is available, requires a NNAGL factor of 1.21 x 621 = 751' or 164' per ton. See further discussion below about southern climates with little heating. Furthermore, northern state systems do not use air conditioning, and after time will withdraw heat only creating a need for extra bore length.

Hydron Module Geothermal Systems

GeoAnalyst® Geothermal System Report

6/16/2010

System 2 - Geo System
Freeman
Essex
Weather Data Location: Bridgeport Sikorsky Memorial CT

Heating			**Cooling**		
Electricity (Hydron Module):	6770	kWh	Electricity (Hydron Module)	2909	kWh
Electricity (Auxiliary):	2	kWh	Average Efficiency:	13.1	Btu/Watt
Propane (Auxiliary):	2	gal	Annual Cost:	$291	
% by Hydron Module:	99.8	%			
Annual Cost:	$682				

Hot Water		
Propane:	112	gal
% by Hydron Module:	62.8	%
Annual Cost:	$259	

Total Annual Operating Costs	
Heating:	$682
Cooling:	$291
Hot Water:	$259
Total[1,2,3]	$1,231

Design Heating Load:	55000	Btu/hr	Design Cooling Load:	36000	Btu/hr
Indoor Design Temperature:	70	°F	Indoor Design Temperature:	75	°F
Outdoor Design Temperature:	12	°F	Outdoor Design Temperature:	84	°F
Heating Electric Rate:	0.10	$/kwh	Cooling Electric Rate:	0.10	$/kwh
Propane Rate:	2.30	$/gal			

Hydron Module Model	H072	H-Series with hot water generator		
Water Heater:	Propane	Balance Point	-1	°F
Auxiliary Heat:	Propane 90%			

Loop Type / Soil: One Vertical U-Tube, Polyethylene SDR-11 1-1/4" / Average Rock

Bore Depth:	350	ft	Deep Earth Temp:	53	°F
Total Bore required:	621	ft	Annual Temperature Swing:	22	°F
Minimum Loop Temp:	31	°F	Phase Shift:	40	Days
Maximum Loop Temp:	100	°F	Soil Conductivity:	1.4	Btu/hr-ft-F
Average Heating Loop Temp:	47.4	°F	Soil Diffusivity:	0.04	ft^2/hr
Average Cooling Loop Temp:	77.2	°F	Pipe Conductivity:	0.226	btu/hr-ft-F

1 Total annual operating costs includes heating, cooling and hot water. Base electric use (electric use other than heating, cooling and hot water) is not included, and will vary depending upon lifestyle. Total annual utilities equals heating, cooling and hot water costs plus base electric use.
2 The operating costs shown above are considered to be an estimate due to the variability of living habits, weather, and system installation.
3 This software uses the latest algorithms from IGSHPA (International Ground Source Heat Pump Association) for ground loop sizing. Operating costs are based upon IGSHPA and ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) algorithms. All calculations are based upon Hydron Module equipment, and may not be [illegible]

Figure 6 Sample Software print out.

Design Plans

8 boreholes serving 2 buildings. Each loop circuit connects to a manifold.

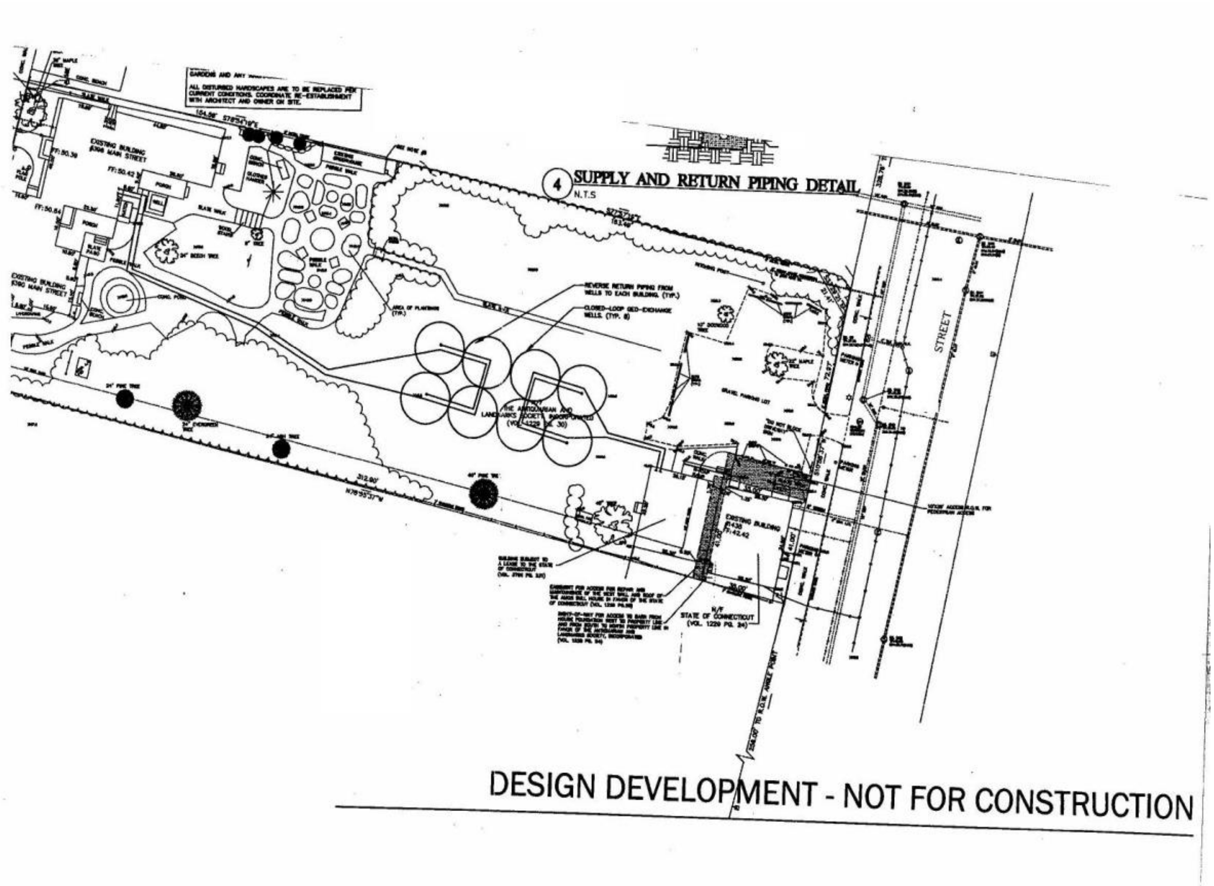


Figure 7

Note the separation of boreholes from each other and preferably from the potable drinking water well (figure 7). Each state has different regulations governing boreholes. In Connecticut, boreholes must be distant from septic systems by legislation, but not distant to water wells, pending passage of regulations developed by well driller associations and regulators. Consult your local regulations. In Georgia, grouting was required starting in July 2010. Normally, building inspectors do not have geothermal jurisdiction outside of buildings.

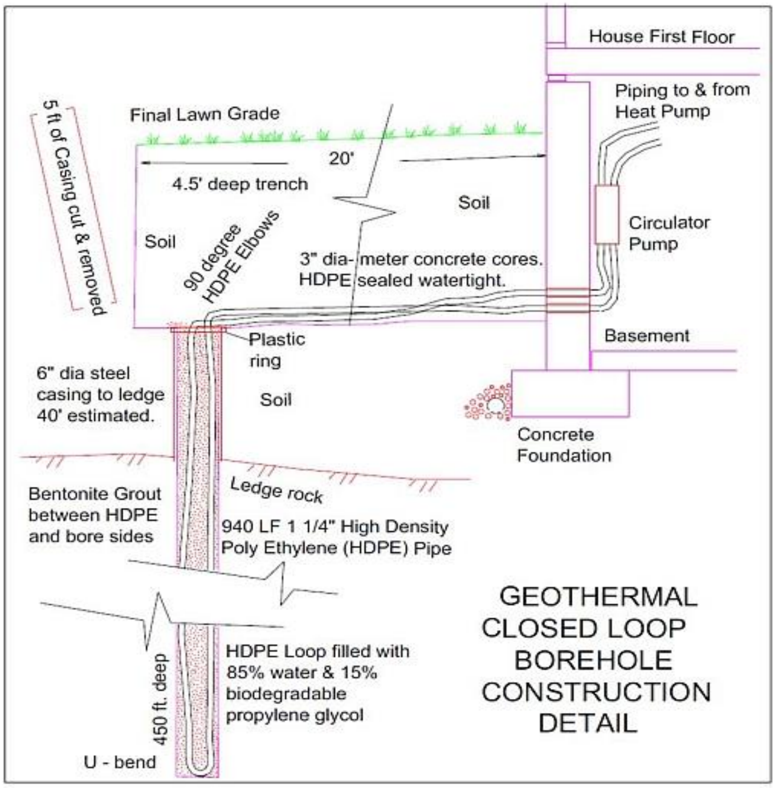
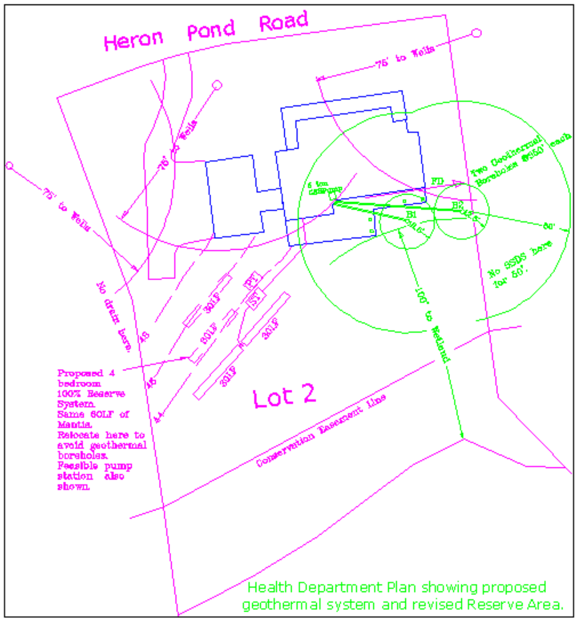


Figure 8

In the next image (figure 9, right), it is legal for the water well line to share the borehole trench, entering the building just 9” apart. But freezing of the pressurized water line is a concern. The propylene glycol in the loops will not freeze if the loop and surrounding soil goes to 25 degrees and forms frost. So, the after the fact, the certifying installer requested a separate trench to be dug for the water line. Loop Frost in wet sand has caused uplifted patios.



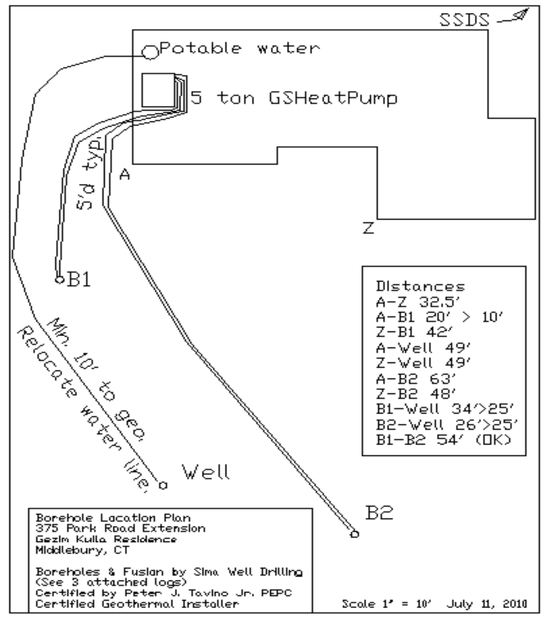


Figure 9 Above left: A colored Autocad design with 2 green boreholes for a house. No manifold.

Placing boreholes too close to potable water wells is also discouraged with a concern that *" ... studies have shown that larger closed loop systems affect the temperature of the aquifer, resulting in an increase in the overall bacteria counts in the groundwater (1). Therefore, there is a potential for the promotion of pathogenic microorganisms. A borehole can also act as a connection between different aquifers or a zone of contamination and an aquifer. This would allow contaminants to flow into an uncontaminated aquifer, resulting in contamination of both aquifers."* (Connecticut, March 5, 2007)

But for boreholes that are properly terminated below the surface, proximity to structure is not an issue. Indeed, in many new homes, the boreholes are drilled beneath the house before its basement or crawl space is poured. Clandestine homeowners who drill a 50' deep well point in their basement and run this water through an open loop heat pump with cupronickel heat exchanger and suitable filtration should check with their sewer departments before discharging this 1 ½ gpm per ton amount into their sanitary sewer pipe.

For southern climate commercial projects where there is an imbalance of minimal heat extraction versus significant heat rejection (due to motor heat, etc.), a hundred million BTUs sent into the borehole loop field might have only fifty million BTU's or less extracted during heating season. Over time, heat builds up in the deep earth. After a few years, entering water temperature rises and lowers efficiency, unless the NNAGL (Normalized Net Annual Ground Energy Load) factor is applied to account for this and provide extra borehole length (1.01 to 2.0). Similarly, up north, systems that use only heating and not air conditioning must upsize for good performance, if heat withdrawal (like in a bank) exceeds heat deposits. See chapter 5 of the IGSHPA manual for these charts and refer to software that computes annual heating loss and gain when one inputs the closest city for weather data.

Drill, Set and Grout

After a design is established, boreholes are ready to be Drilled, Set and Grouted. Conventional drilling is with 6” or 5 ½” wide drill bits similar to equipment used to drill water wells. 4” bits in soils are common too. A unicoil, consisting usually of 1 ¼” inside diameter 3034 HDPE (or more expensive PEX piping) with a U bend on the bottom, is set into this 6” wide hole. Heat fusing of U bends is no longer routinely done but is supplied by the pipe manufacturer. 3/4” U bends are also common, but in Connecticut it is almost always 1 1/4”. Into a 350’ deep borehole might go a 710, meaning 700’ of pipe with a U bend fused to the bottom and 5’ tails sticking out of the ground for factor of safety length.

Figure 10 Left: A Unicoil or U-tube ready to be set into a borehole. Right: Various types of U-bends placed at bottom.

Sometimes coils come crimped near the end so that they are air tight. When cutting off the crimp, listen for an air hissing sound guaranteeing the loop is undamaged and can hold pressure. Check white lettered printed labeling information every two feet on the loop. U bends are often strengthened so that when pipe drops onto solid rock bottom, it will not crack. Drillers who cut loop pipes to fill with water can heat them with a torch and crimp them closed temporarily to avoid debris falling inside a loop pipe.


Figure 11 Left: PEX pipe molded U-bend. Right: 4 pipes in a hole, double PEXa U-bends.

Drilling

Figure 12 Typical drilling operation. This job was shown on the previous software sample (fig. 6) and site plan (fig. 7).

Drilling ground source boreholes utilizes the same rig that drills water wells. For soil over bedrock ledge, 6” steel casing is installed in the northeast, but less so nationwide. 20’ rods are lifted onto a carousel. The current hole is 25’ from the completed borehole to the left. In the photo above, see the Unicoil (or U bend) leaning against building to the right. Expect about a yard of drill cuttings to wash to the surface for each 100’ of bore. A silt fence is to the left. Water control that does not enter wetlands or storm drains is a major planning consideration. It is important that drillers log the formation characteristics for the follow-up grouter crew, such as “Big Seam at -265’!” Note the Roller sling on the ground that will be used to assist in placing the U bend at the bottom.

Set U-bend or Unicoil

Figure 13 Driller uses roller sling for ease of operation.

A cable pulls the loop and roller above the bore where it is unrolled (figure 13). A steel rebar is sometimes taped to the straightened U-bend so that it hits the bottom first, and not the U-bend, which could crack on impact. Setting the 1 ¼” unicoil loop pipe into the borehole can be dangerous in a dry hole condition. Gravity can unroll the loop quickly, catching a worker’s fingers against the steel casing that is installed to prevent collapsing near the surface. In water filled boreholes, the loop pipe is also filled with clean water, so it does not become buoyant.

Figure 14

Sometimes workers push the loop into the borehole, and sometimes it is fed by reel. One ingenious geo installer invented a machine with one or two rubber tires on motors that turned together with the loop pipe between the treads, to push it down the borehole

Figure 15 Left: A set of gages. Right: Sealed end.

Once the loop pipe is set, pressure gages are connected to be sure the HDPE (rated at 160 psi) is not leaking. The ends are sealed to be sure no material enters the loop (and settles at the bottom U bend.) Sometimes these caps are heat fused to guarantee no contamination.

Water or Air testing standards for smaller jobs vary with 40 to 100 psi common, when operating pressure will be only 20 psi or so. Test twice. Once before grouting, and once inside the building.

Figure 16 Geo-clip.

A geo-clip has a steel spring to separate both the "hot leg" from the "cold leg" within the 6" wide borehole. The third white top piece shown (figure 16) holds the tremie pipe for the grout. As the tremie is lifted out, the steel spring pushes both legs of HDPE out toward the edge of the borehole, where it is closer to the rock, and separated from the other HDPE. By placing geo-clips every 10' or so, better ground exchange is achieved. But careful installation is needed `to avoid a cluster of clips appearing at the surface. Once common, geo-clips are less used and replaced with dog bone clips, etc.

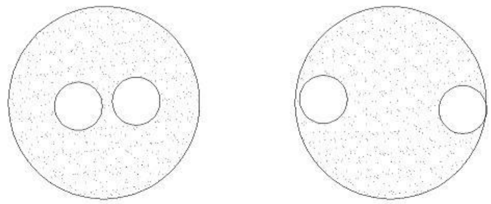


Figure 17 Cross-sectional Drawing of 1 1/4" loop pipes in a 6" borehole.

The 1 ¼” loop pipes in a 6” borehole to scale (figure 17), showing how the geo-clip (or alternate separating mechanism) results in the image shown to the right. This forces the loop pipes against the borehole walls, and away from each other, for better heat transfer to 1.4 rock, not 1.0 grout. Alternate systems are also available such as a coaxial HDPE pipe within a pipe, or a twisted version with several 1 1/4” pipes wrapped around a central 2” HDPE for grout placement. *http://www.agreenability.com*

Grout

Today’s protocol requires economical grout to fill the void between the 1 ¼” loop pipes and the 6” diameter borehole. Cuttings are not suitable for annular backfill placement in boreholes. They could allow bridging and a void within the deep bore. Air or water void thermal conductivity is inferior to TC through solids such as bentonite and silica.

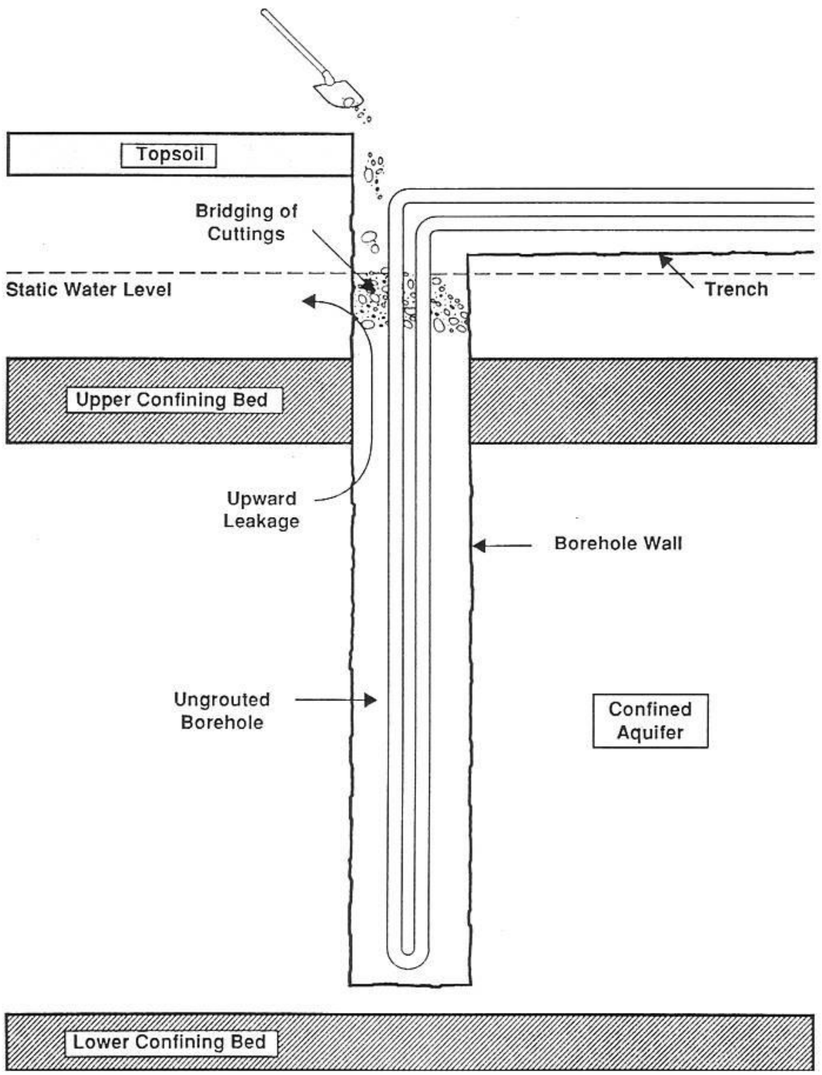


Figure 18

Grout is used for its superior thermal conductivity to allow heat to move freely between the water and propylene glycol or methanol solution and the earth coupling. During application, grout must always be placed from the bottom up to assure no bridging, and corresponding voids. Low permeability Grout is required in many jurisdictions to protect groundwater movement between aquifers. Some New Jersey jurisdictions required Portland Cement based grout (with 5% bentonite to reduce shrinkage away from the loop pipe and soil or rock). This is due to a previous incident where a sweet ethyl alcohol antifreeze from a geo-loop once escaped past a bad fusion joint and bad grout seal and entered the water table where it was reportedly found in nearby school drinking faucets! While suitable for above ground boilers, ethyl alcohol should not be placed in the earth. Biodegradable propylene glycol (found in toothpaste and many consumer products) is suitable. Nearly every other state (except Kentucky which still allows low *K* cuttings) requires or recommends western Montmorillonite Bentonite based grout for enhanced permeability, conductivity and non-shrinking. Bentonite grout is superior to cement grout, because cement is not as good a heat conductor. Using PG and redundant protective grout assures no pollution or aquifer migration. Sand grout is described next, but graphite grout without sand has been used in recent years.

The next images show actual grouting operations in sequence with explanation of each step.

Figure 19 1 1/2" HDPE tremie pipe on a spool at the back of the truck. It is connected to the mixer near the supply of bagged silica sand and bentonite grout mix.

Figure 20 Tremie pipe pushed to the bottom of the 350' deep borehole.

The 400' length of tremie pipe leaves 50' on the spool. Temporarily, three pipes share the 6" space. Sometimes the wheel is used instead. (If Geo Clips were used, (or not) the tremie could have been inserted along with the U-bend loop pipe.) Air is allowed to escape from the other end of the tremie (also HDPE) pipe, so it does not resist insertion down the hole. Filling it with grout gives needed weight to go down.

Figure 21 Twin rollers attached to the casing make insertion easier.

The steel casing is left in place (figure 21). Although expensive, it has good thermal conductivity. No air pocket is anticipated between it and the surrounding soil. But if the hole is stable, no steel casing is better. Plastic casing, if ever used, must always be removed because of its poor thermal conductivity.

Figure 22 Grout is ready to be mixed and pumped in to borehole.

Figure 23 Water enters the mixing hopper as controlled by the valve.

Figure 24 Adding silica sand and bentonite grout.

Five bags of silica sand are added for each bag of bentonite grout (figure 24). This fills about 23'. Planned Viscosity allows good penetration and proper hydration. The borehole uses 15 bags of bentonite grout and 75 bags of silica. Each bag is cut open and emptied into the mixer. Five empty garbage bags are stuffed into each bentonite bag to track usage or for end of day inspection.

Figure 25

At the controls, the driller/grouting operator can read pressures and tell if grout is escaping into nearby seams (figure 25). If so, then extra grout must be used and the tremie pipe is not raised until pressure allows. Grout pressure should not be so high as to stress the HDPE. During grout setting, the heat of hydration of the warm mixture could rise to 120-130 degrees and weaken the HDPE.

If grout is escaping, be sure that it is not entering a nearby water supply well, nor entering an adjacent borehole. For this reason, maximizing separation distance (to 25'+) is very important. Grout can bridge an adjacent borehole above its bottom leaving an air or water/ice cylindrical void trapped below. Drilling and Grout pumping pressures might loosen rock fragments, and this might prevent the tremie pipe from reaching its bottom. The uninspected driller can only do his or her best to grout above the intrusion. Of course, U-bend insertion into the freshly drilled hole with labor intensive geo-clip/tremie assembly and immediate grouting negates this problem. But sometimes the grout crew is separate and there is inadequate room for driller and grouter on site.

Figure 26 An electric motor winds the spool to raise the end of the tremie pipe as the grout is added.

1. At first the clean water in the hole is expelled.

2. Then the grout colored water flows out, as the entire borehole is filled solid with only the two 1 1/4" loop pipes, and the grout.

3. After the grout sets, an excavator digs a 4’ to 5' deep trench to the building and the steel casing in ledge, will be burned off 4'-5’ below the surface.

4. Bentonite grout is not set even days later, like cement grout. It feels like wet, sandy peanut butter. Here it has slumped after the 5' casing was cut.

5. 90-degree elbow bends and tees are socket heat fused onto each vertical loop pipe end, to run a horizontal HDPE into the building. Alternatively, the HDPE can be carefully bent 90 degrees and butt fused horizontally.

6. The Horizontal Reverse Return with 2" and 1 ¼" HDPE connects the boreholes to the building. It is now ready for backfilling.

Bentonite Grout Thermal Conductivity will be 1.00 BTU/hr.-ft.-°F in this 1.4 rock. The important information on the bag is readable in the large picture below (figure 27).

Note that *K* in column 1 can vary from 0.4 to 1.0, depending on how much silica sand is mixed in. Software program results easily show that higher grout *K* = lower required borehole lengths. A 1.0 or 1.2 *K* grouted borehole might require much less depth than a 0.4 *K* filled borehole. So, good silica aggregate is a very cost-effective filler. Graded masonry sand might not be as suitable as dirty sand with desirable fines for higher density. And rounded, not angular sand is pumped easier through a gear pump, a double action piston pump, or a progressive cavity or diaphragm pump. Consider new graphite grout using less heavy sand bags as well.

Figure 27 Bentonite grout bag. Note Column A, Thermal Conductivity.

Figure 28 Approved Sand Aggregate.

Bags provide certain convenience, but also added expense. If a quarry of sand was tested, it could be transported by truck and shoveled into the hopper at less expense. (Think "Super Sock" hanging from a Pettibone.) Conventional Concrete batch plants and ready mixer truck fleets are not set up to provide economical bentonite grout.

To be sure grout was mixed with proper water gallons amounts and bentonite to silica ratios, Grout Samples can be tested for free at:
http://www.geoproinc.com/services/grout_sample_testing.html

Figure 29 Left and Right: A grout rig "down south" in Oklahoma.

Figure 30 A grouting trailer for sale at the South Atlantic Well Drillers Jubilee Expo.

Water well drillers expanding their services to geothermal boreholes must invest in paddle mixers and grout pumps (positive displacement progressive cavity pumps that do not clog). With this equipment and their drill rigs, they can provide complete ground exchange product.

Heat Fusion

Borehole loops can be either bent at appropriate radii into the horizontal trench toward the building or outside header or can be connected by a 90-degree socket fusion elbow. While PEX pipe can have a non-fused outside connection per the manufacturer, HDPE can only be heat fused. Most borehole operations, unlike small continuous horizontal trenching under 1000’ lengths, require heat fused connections.

There are many types, but two standard ones in the geo-field are the butt fusion and the socket fusion. A socket fusion kit is shown for sale with male and female heating elements

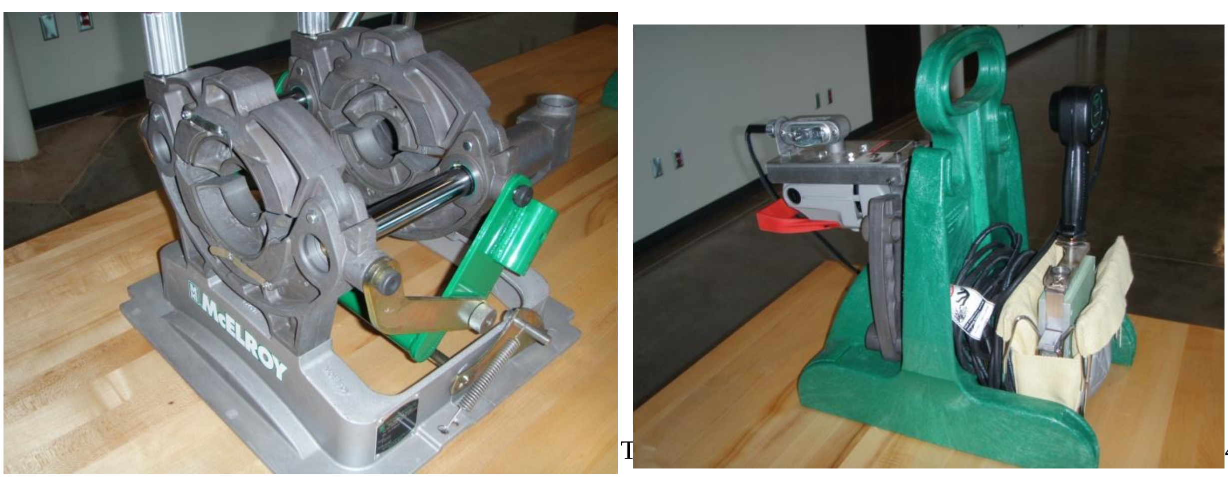


Figure 31 Left: Butt Fusion, Right: Socket Fusion

Figure 32 Socket Fusion kit for sale.

(figure 32). Couplings and elbows are purchased separately. For fusing, heating is to 400-450°F for a Butt Fusion and 490-510°F for a Socket Fusion.

Figure 33 Well driller achieves his fusion certification by holding a coupling to an HDPE pipe for 30 seconds until the fused joint is stronger than the regular 160psi pipe. Tested by borehole expert Gregory Wells.

A new development in coupling technology that replaces conventional heat fusion is this electric based coupling with copper wire inside, which is heated to fuse pipe sections without the need for a fusion machine kit. Conventional couplings are more costly.

Figure 34

A new radio frequency fusion technique offers couplings, elbows and tees priced like socket couplings, elbows and tees: The Triton RF Electrofusion Welding System: http://www.iapmo.org/Documents/ETS_PowerPoint_Presentations/ETS%202012/Barrett_Fusion_Welding.pdf
http://www.iapmo.org/Documents/ETS_PowerPoint_Presentations/ETS%202012/Barrett_Fusion_Welding.pdf

Manifolds

Smaller projects can avoid manifolds especially buried outside, where faulty circuit loops cannot easily be isolated and detected. For large loop fields with many boreholes, each borehole circuit is connected in parallel to a manifold either located in the building or buried outside.

Figure 35 Manifolds

Loops in parallel can achieve desirable turbulent Reynolds Number flow velocity for varied size pipe diameters. Manifolds may be located in underground vaults for access to assure each circuit is flowing at proper pressure. Sometimes a third type of fusion, saddle fusion is used, with the manifold opening drilled out after fusion.

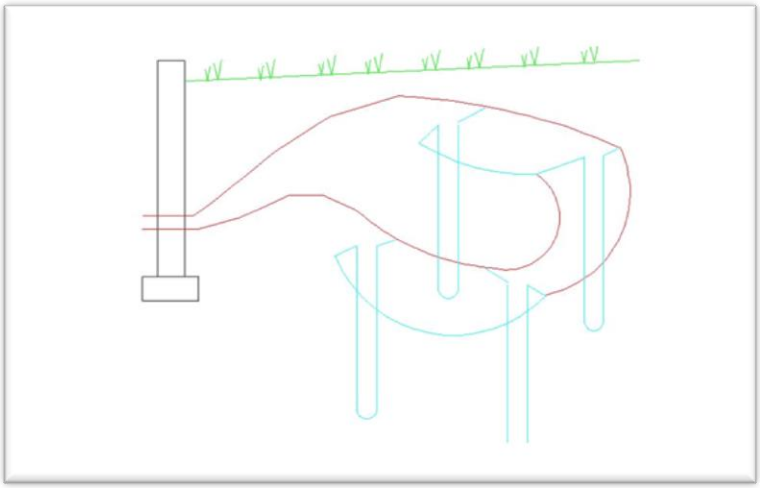


Figure 36 A simple Reverse-Return Manifold Heater. Red HDPE is 2" diameter. Blue HDPE is 1 1/4" diameter.

Each blue borehole (figure 36) at 450' depth could supply 3/4 of the 3 tons = 36,000 BTUH normally rated Heating Capacity of a typical 4 ton heat pump that also generates heat from the electrical input. That heat pump would have about 48,000 BTUH Cooling Capacity, and hence the label 4 ton, even though Heating Capacity on all units is less.

Total 16-ton of heat pumps would handle a large, older, air leaking residence, or a small commercial building. For a small well insulated house, a single borehole is adequate. All piping shown is at least 4'-5' deep in frost environments. But horizontal trenching by conservative tradition is not counted for ground heat exchange credit.

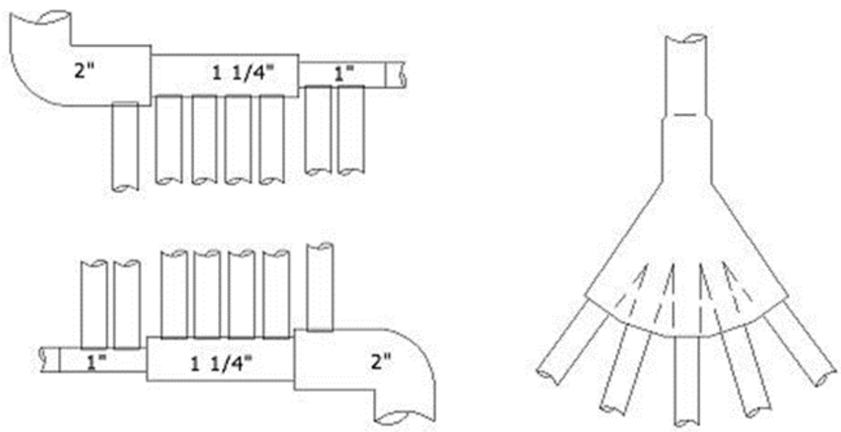


Figure 37 Manifolds.

The standard Reverse-Return manifold is on the left in figure 37. Pipe sizes step down to reduce risk of air entrapment, and balance flow to the borehole ¾" or 1" circuits. To the right in the same figure, www.geosolarproducts.com developed a new axisymmetric manifold.

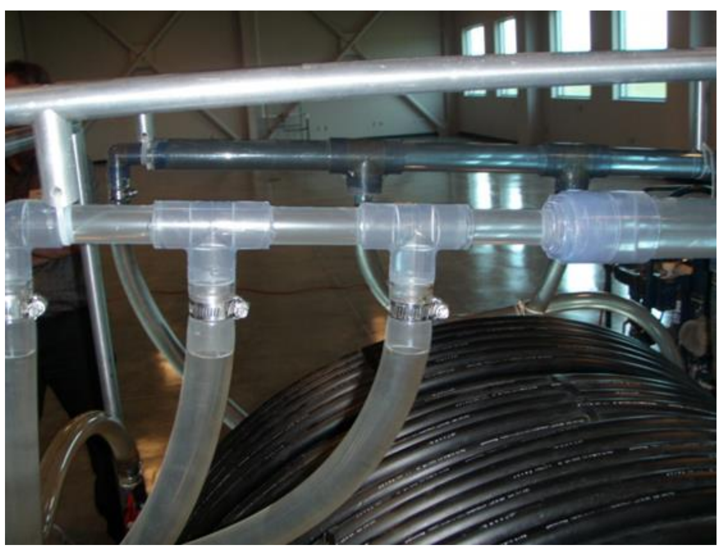


Figure 38 Demo unit at IGSHPA Headquarters.

In this demonstration unit, at IGSHPA Headquarters (figure 38), the manifold pipe is not stepped up in size.

When activated, it traps air that can damage the propellers of a flow center circulating pump, such as those made by Grundfos, Wilo or Bell & Gossett. Through the transparent tubing, students can see air bubbles not normally visible through (bacteria killing), dark black HDPE.

Figure 39 Prefabricated PEX pipe manifold.

This prefabricated PEX pipe manifold limits the circuits and distances to avoid air entrapment. Larger manifolds would step up in size. The future trend appears to be more factory assembly, such as U bend coils instead of field heat fusion of two 90 degree elbows, and fabrication of entire manifolds and balancing valves.

Loop pipes entering a building need to be watertight, as explained in the horizontal loop SUNCAM course 029.

Recommended procedure is hydraulic cement from the outside. But since it could shrink and crack under the loop temperature fluctuations, cover it with tar.

On the inside, tar can be placed in the center of the concrete cored wall, and link seals installed for a rubber connection from the loop pipe to the concrete (figure 40).

For a 2” HDPE loop, drill a 4” core, and install 6 link seals. See course 029 with wet core drills.

Figure 40

Figure 41

Once the loop is installed through the foundation wall, interior piping need not be fused HDPE, but using fused HDPE would be good practice. If connected to rubber hose or Schedule 80 PVC, be sure to use the proper brass connection, such as the one shown in figure 41. The PVC expansion and contraction with temperature changes could cause a leak. Additionally, a small loss of fluid can allow undesirable air into the system. Authorized heating of the brass barb before insertion into the HDPE followed by clamping will assure a tighter bond that does not leak.

Miscellaneous borehole features

Figure 42

High tech markers such as this 4" diameter globe (figure 42), are used to mark the ends of large borehole fields. Rather than tracer tape, a special tracking device from above can detect this buried marker at the perimeter of a buried geo system. With more borehole fields being installed under parking lots, and elsewhere, knowing their future location, without having to excavate nearby, is thus planned.

Conclusion

The outside ground coupling to the earth is an important component of the ground source heat pumping system. The heat pump accepts the loop water at its required entering temperature (EWT) and gallons per minute flow. Nothing else impacts it as much as these two features. A robust loop field harvests adequate amounts of thermal energy to run the heat pumps efficiently. It is up to the outside loop designer and driller/installer to assure that good contact with the deep soil and rock is maximized. Design professionals working with HVAC contractors, well drillers and excavators can tap this abundant resource to decrease America's dependency on fossil fuels.

The Statue of Liberty's retail pavilion was recently converted to geothermal heating and cooling, featuring open loop drilled by the white and green rig, shown in the lower left.

Very little land area is required to access the heating and cooling capabilities below ground.

You are urged to attain your IGSHPA Installers, Designers or Drillers certification and build the energy efficient systems we will all need tomorrow. As more and more Ground Exchange Boreholes are drilled, the costs will continue to come down and installation efficiencies will rise. This will encourage more choice toward the necessary renewable energy use of the land beneath us. May ground source heating and cooling technology be a source of "Green" money profits for you designers and drilling contractors, and may you please your customer clients by installing these much needed efficient and professionally planned systems.

Tower Up!

End of course.

ADDENDUM

Table 1 <u>Thermal conductivities of various materials at 77 F temperature</u>

Material	(K) BTU/ft^2 /ft hr ^{o}F
Air	0.014
Aluminum	145
Asphalt	0.43
Brick dense	0.76
Brick work	0.40
Carbon dioxide	0.0084
Cement, Portland	0.17
Cement, mortar	0.99
Chalk	0.05
Chrome Nickel Steel (18% Cr, 8 % Ni)	9.4
Clay, dry to moist	0.0.086 - 1.04
Clay, saturated	0.34 – 1.44
Concrete, light	0.24
Concrete, stone	0.98
Copper	231
Cork	0.04
Cotton	0.017
Earth, dry	0.87
Fiberglass	.023
Glass	0.61
Gold	179

Material	(K) BTU/ft^2 /ft hr ^{o}F
Granite	0.98 – 2.3
Ice (0^{o}C, 32^{o}F)	1.26
Iron	46.2
Limestone *(at the surface?)*	0.72 - 1.02
Mercury	4.6
Mineral insulation materials, wool blankets	0.023
Oil, machine lubricating SAE 50	0.09
Sand, dry	0.09 - 0.14
Sand, moist	0.14- 1.15
Sand, saturated	1.15 – 2.3
Sandstone	0.98
Sawdust	0.046
Silver	248
Snow (temp < 0^{o}C)	0.029 - 0.14
Soil, with organic matter	0.09 – 1.15
Soil, saturated	0.35 – 2.31
Styrofoam	0.019
Vermiculite	0.033
Water	0.33

Note that water is about 24 times as conductive as air. Thus, air is an insulator for building surfaces. In the ground, air voids that act like insulation are to be avoided. Moist soils are superior, and well graded materials filling void spaces are better than dry sand. Boreholes in rock generally have higher thermal capacity than soils.

Soil Thermal Texture Class	**Thermal Conductivity**
	BTU/ft. hr. °F
Dry Sand or Gravel	0.44
Silt	0.96
Clay	0.64
Loam	0.52
Saturated Sand	1.44
Saturated Silt or Clay	0.96

Sample Regulations from Connecticut

(not on exam) Proposed and being updated to separate the HDPE from the top of the casing http://www.ct.gov/dcp/lib/dcp/pdf/laws_and_regulations/well_drilling_and_geoexchange_regs_-_final_10-20-10.pdf

Sources

- Connecticut recommendations for regulation of geothermal wells http://www.ct.gov/dph/lib/dph/environmental_health/pdf/Geothermal_Well_Paper_2-_11report.pdf March 5, 2007

