

# **Geothermal Heating and Cooling for Small Commercial and Residential**

**(Trench Design for Ground Source Heat Pumps)**

**by**

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**Course 029**

**4 PDH (4 Hours)**

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## Introduction

Harvesting Ground Source Energy is an important topic today. Design and Construction Professionals who have solved past infrastructure problems are in a unique position to help people reduce dependency on oil and gas. Ground Source Heat Pump Systems, such as the ones discussed in this course, extract heat from the ground in winter and they reject heat to the ground in summer. They use smaller amounts of electricity than air source heat pumps and avoid fossil fuel flame combustion in the building served. The terms *geothermal* and *ground source* are interchangeable, but utilizing deep earth geothermal from hot magma to make electricity is a topic separate from this course.

Whether the goal is to reduce CO<sub>2</sub> emissions or not, tapping ground source energy makes good sense on its own. If the proposed federal expansion of nuclear power plants is accomplished and electric generation gets even less expensive, geothermal power becomes the perfect complementary partner. As a result, ground source heat pump operating costs will compete aggressively against heating oil, gas or plain electric heating and air cooling. Property owners can choose the source of energy they want for their comfort. For those interested in cleaner air from less combustion, or reduction in CO<sub>2</sub>, here is the description of that process.

Our Carbon Footprint results from the chemical reactions that occur especially during the combustion process. We each put tons of Carbon Dioxide into our atmosphere. Every gallon of gasoline burned (or heating oil or natural gas equivalent) causes huge quantities of CO<sub>2</sub> to be emitted. For example, gasoline weighs about 6 pounds per gallon, compared to heavier water at over 8 lbs./gal. Eighty percent of gasoline (5 pounds) is Carbon. From the Periodic Table of the Elements, one carbon atom with 6 protons and 6 neutrons for an atomic weight of 12 combines with two Oxygen atoms, each



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having 8 protons and 8 neutrons for a weight of 16 each. The new molecule has weight of 44. Every five pounds of Carbon produce 18 pounds of CO<sub>2</sub>. A 20-gallon gasoline tank produces 360 pounds of CO<sub>2</sub>. Similarly, the 500 or so gallons of #2 diesel fuel oil that can be saved each year with a three-ton ground source heat pump, results in at least 4 tons less of CO<sub>2</sub> going up the chimney.

The Utility Companies endorse geothermal systems and have offered financial incentives to owners who install them. This is especially important when peak demand for electricity occurs on hot summer days and many people run their air conditioners at the same time. The geothermal customers are only using about half of the electrical power that the air source heat pump and other air conditioner customers use.

The geothermal loop air conditioning users are moving heat out of their buildings into the ground, instead of converting electricity to cool their indoor air. This fraction of electricity needed to move cool air into a building compared to electricity needed to produce conventional air conditioning is the Energy Efficiency Ratio (EER). For the reverse heating mode, the ratio is known as the Coefficient of Performance (COP). Typically, a ground source heat pump with COP = 4.0 only needs one quarter of the electricity to produce the same heat as an electric baseboard heater. Therefore, a \$100 electric bill becomes \$25. Similarly, a pickup truck getting 15 miles to the gallon that was suddenly experiencing a COP of 4.0 would get 60 miles to the gallon for the same sized vehicle.

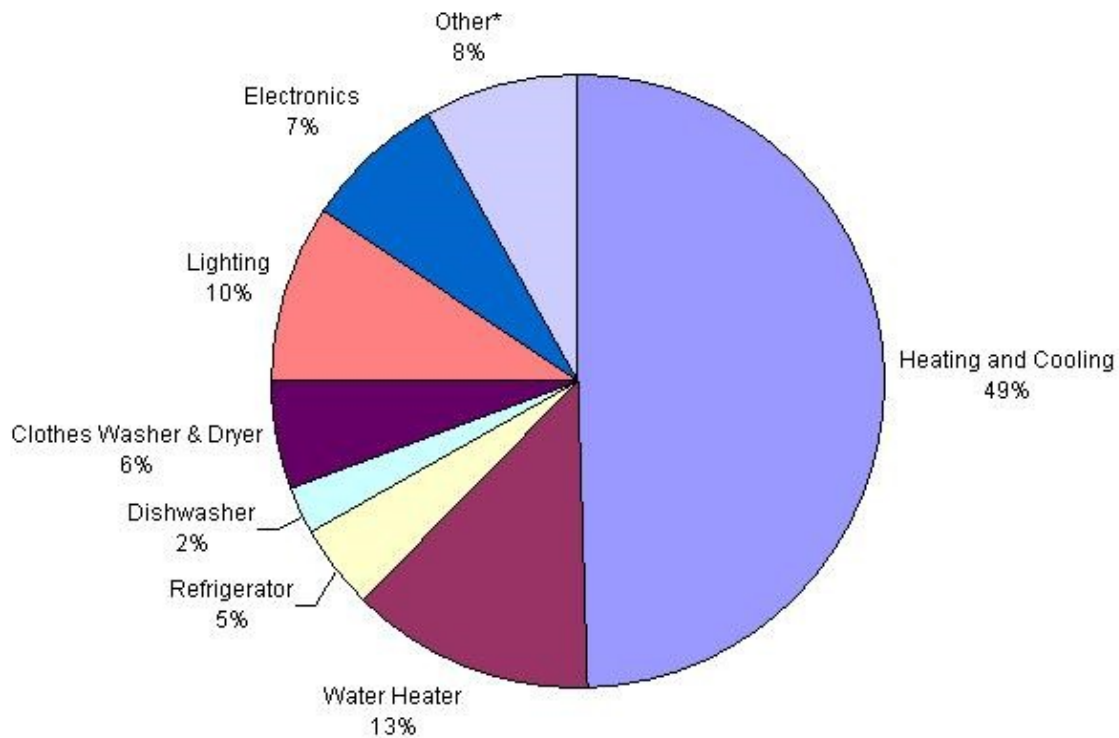


A modern ground source heat pump supplies winter heating and summer cooling in the same underground loop. The extra cost for this dual capability is minimal. Seasonal recycling replenishes the heat and coolness stored in the soil for the opposite season. Both processes utilize the same liquid water and antifreeze solution thermal exchange medium causing the ground essentially to act like a giant storage battery for BTU's. Some compare it to a bank making summer heat deposits and winter heat withdrawals with good systems being in balance.

In the winter, Ground Source Heat Pump (GSHP) users require more electricity than when they were burning fossil fuels. But electricity usage is not problematic for the utility companies, because the demand is below that of peak summer levels. Those who convert from electric heat to GSHP heat save the Utility Companies and themselves almost  $\frac{3}{4}$  of their electrical use.

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The cost savings for moving heat instead of producing it can be substantial, usually cutting costs by half to three quarter. Depending on installation costs, payback can be 10 years at current fuel prices or 5-7 years if crude oil spikes again. Heated buildings that convert to ground source use the free solar energy applied to their lawns and meadows. Savings realized as the result of smaller heating and cooling bills provide more long term return for the investment versus the savings from low wattage lighting or the use of solar panels, which require huge subsidies to be competitive.



**Figure 1 Typical Residential Energy Use**

As an added bonus, home boilers and furnaces experience less wear and tear and there is no hazard from fire or smoke. Sometimes, a conventional heat pump air conditioner in good condition that has been replaced by a GSHP can be removed and sold as used equipment to a home where geothermal is not practical.

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Micro-economically, the labor dollars spent installing an underground closed loop go to local excavating contractors or are kept by thrifty owners that have access to a backhoe.



**Figure 2 Excavation contractor at work.**

There is a real need to provide building owners and their designers with the information they seek to retrofit their building as cost efficiently as possible. Most internet web sites describe new or larger commercial construction. This SUNCAM course focuses on the outside ground issues associated with smaller, existing building systems. The advanced SUNCAM course 045 addresses interior work involving the geo heat pumps. Course 091 discusses drilling vertical boreholes.

Although most geo installations utilize drilled well boreholes to save on loop design effort, a good horizontal trench installation will be just as effective as a vertically drilled borehole. Costs can be  $\frac{2}{3}$  to  $\frac{3}{4}$  of that to drill, for the right soil and property situation.

Upon completion of this trench course, one will be able to design and oversee the installation of an inexpensive underground source heat loop that will result in efficient heating/cooling energy for a small building. By taking the approved installer training after the course from IGSHPA (International Ground Source Heat Pump Association), one can become

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credentialed, use the more precise IGSHPA methods for design, and benefit by qualifying for rebates, etc. following the installation of a GSHP.

The course follows this outline: Outside Work, Underground Mapping, Soils and Excavation, Length of the Loop, Design Loads and Retrofit coring into the Building.

## 1. Outside Work

A typical Ground Source Heat Pump (GSHP) system consists of two separate projects: Outside (Exterior) and Inside (Interior). For the construction professional, the buried closed loop in the soil is its own undertaking. This buried, closed loop Geothermal Pipe filled with water and antifreeze is the Geothermal Loop Pipe (Loop). In a typical, small building or house retrofit for a GSHP, the inside HVAC contractor expects to install the heat pump indoors after two ends of the buried closed loop have been placed through the walls and are available for hookup. The outside installer's job concerns the buried Loop that starts at the building, winds its way under the lawn in a trench, and returns to the building.

The design steps for the outside buried Loop are:

1. Review the plot plan or survey map to verify that the buried Loop can be contained wholly on the land owner's property without violating deed or easement restrictions.
2. Discuss all buried utilities, landscaping and future land use ambitions with the owner.
3. Determine the soil type and, especially, depth to ledge and ground water.
4. Investigate the BTU heating and cooling loads of the structure for its square footage and its insulation. (Use ACCA Manual J for residential.)
5. Choose the appropriate length and diameter of closed Loop.
6. Draft a plan showing the house on the property and where the Loop will leave and return to the building.
7. As-Built deviations or photos can be taken by the owner for future reference.



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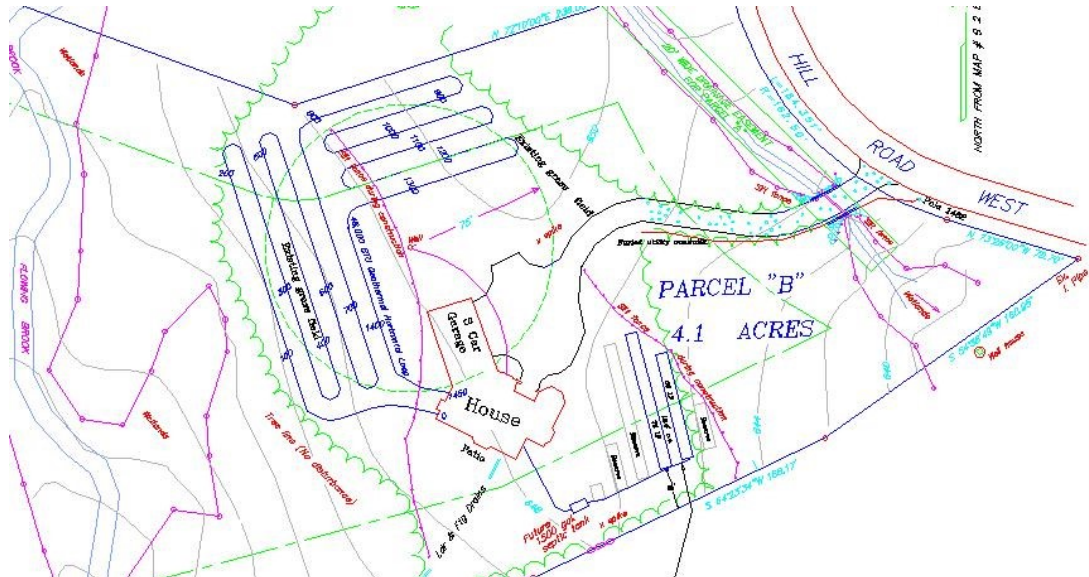


Figure 3 AutoCAD plan of house with 10ft. on center loop field.

For more detail go to:

<http://www.suncam.com/authors/076Tavino/mh-Model.pdf>

Steps 1 and 2 involve mapping practices familiar to engineers and construction professionals. In retrofitting a typical 2000 sq. ft. building, allow at least 1/3 acre of deep soils for trenching. The smallest allowable lot size is probably 1 acre, otherwise consider boreholes or a horizontally bored loop. When considering capital construction cost, it is important to understand that good deep soils immediately make the trenched Loop system more cost effective than drilled wells or DX (Direct Exchange) rock drilling track rigs. A few days of backhoe time is usually less than the cost of well drilling and thermal grouting. The backhoe cost must be substantially lower than the drill rig costs to harvest the deep soil resources, and good mapping skills are needed.

A baseline means test helps the owner to understand that there is a commitment of at least \$18,000 for a modest 1500-2000 sf building: \$10,000 inside and \$8,000 outside. Owners can perhaps lower the cost by doing the following:

- Securing their own permits.
- Drilling through their basement or utility area walls.

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- Installing erosion control measures.
- Helping with the Loop installation.
- Raking, reseeding and watering their lawn, post construction.
- Paying by the hour for the backhoe/excavator could save risk & uncertainty.

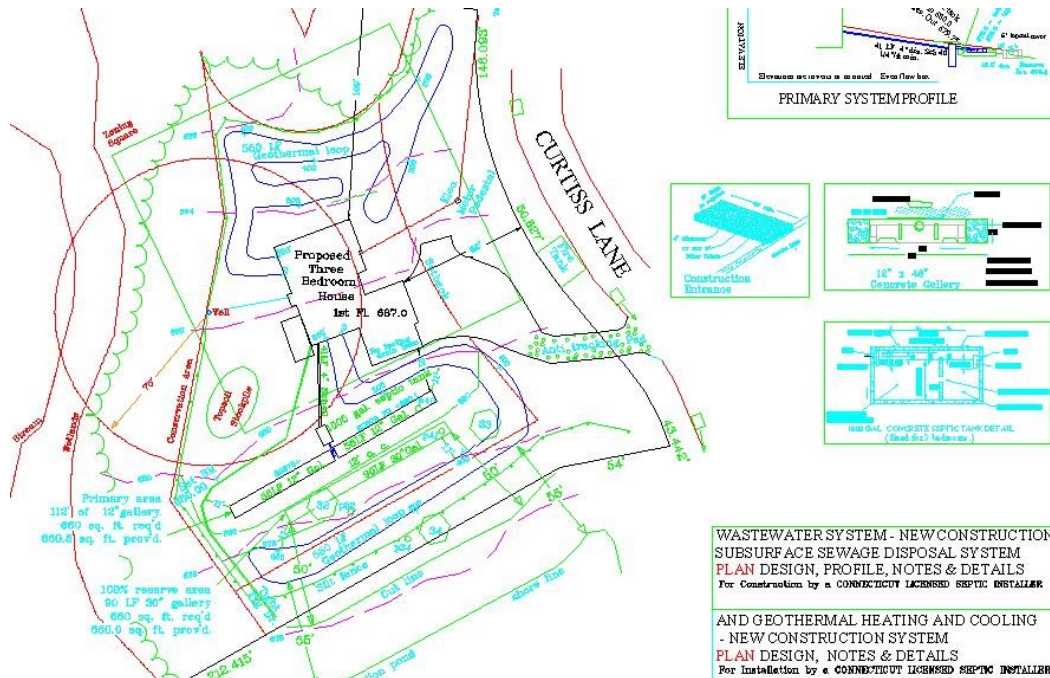
## 2. Underground Mapping

Among the existing or planned buried utilities, there could be underground electric, telephone and cable TV, or internet lines that should neither be crossed nor dug closely. The *Call Before You Dig* toll free numbers provide free markings of some of these critical obstacles. A quarter acre lawn with buried power running up the middle may be unsuitable because loop fields cannot go beneath or cross over live power lines.

Primary and reserve septic systems should be on file at the local Health Departments (along with a percolation test and deep test hole classifications). While some departments allow intrusion into a 100% reserve or expansion area, many do not, and a general practice is to avoid the primary system by 10', 25' down gradient. This is understandable, because an excavated trench that is backfilled with the native insitu soil can have slightly slower permeability when the soil structure is realigned. This could impact the minimum leaching system spread. Additionally, freezing wastewater laterals can hamper proper wastewater digestion. To save work, give early consideration to existing or designed septic systems. In general, avoid the sewer line, especially those built of old clay tile.



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**Figure 4 Two geothermal loop fields with septic system design plan.**

*For more detail go to:*

<http://www.suncam.com/authors/076Tavino/curt-Model.pdf>

By studying these systems, consider past clients with suitable soils, who would be good candidates for a GSHP system. Professionals can use existing digital .dwg files instead of scanning in paper maps to reduce AutoCAD drafting costs.

While there is no regulation of closed loop standards, common sense should prevail. A PE can design an efficient system based on experience, but the project does not generally require a professional engineer's stamp, which makes smaller ground source systems affordable. Check local and state codes to verify the need for professional services. By contrast, borehole drilling is different and does encounter more code restrictions. As a result, inside HVAC contractors are usually under the jurisdiction of the local Building Inspector.

The High-Density Polyethylene (HDPE) water line pipe that connects the drilled drinking water well to the building is like the HDPE Loop, but usually at a lower 100 psi for drinking water, not the specified (160 psi, SDR-11 wall thickness, PE-3408 resin A) quality of Geothermal Loop pipe. Separation distance is essential, especially in northern climates, to

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prevent issues with nearby plumbing. As a Loop draws heat from the ground, the soil near it can freeze and create a frost bulb with a radius of several feet. Just as footings must be 3'-4' deep below the surface in northern states because of frost penetration, a Loop should not be located within 2' of a 4' deep pressurized domestic water line that is not designed to withstand freezing temperatures and associated bursting forces. Data on the magnitude of frost bulbs is being sought, but until known, the recommendation is to maintain a 10'-20' distance.

Geothermal Loop construction methods seek to minimize interference between adjacent Loop lines in the following manner:

- Keep Loops in trenches at 10' on center. (If 6' OC, add 8% more loop length, or use IGSHPA tables to be more precise.)
- When bending pipe around corners at 5' radius, backfill by hand shovel.
- Never crimp a pipe.
- Leave Loop loose on the trench bottom to compensate for expansion and contraction.

Here is how BTUs are moved from the ground to the house.

First:

$$\begin{aligned} \text{Flow} &= \left( \frac{\text{GPM}}{\text{Tons}} \right) \times \text{Heat pump unit tons} \\ &= \frac{3\text{GPM}}{\text{Tons}} \times 3 \text{ tons} \\ &= 9\text{GPM} \end{aligned}$$

where,

Heat pump unit tons = 3-ton unit

Unit circulating capacity = 3gal/min. per ton

Then, we know that 1 BTU is defined as the amount of heat required to raise the temperature of one pound of water by 1°F. So, to find the total pounds of water and the BTU/hr.:

$$\begin{aligned} \frac{\text{lbs of solution}}{\text{min.}} &= \left( \frac{\text{lbs}}{\text{gal}} \right) \times \text{flow} \\ &= 8 \frac{\text{lbs}}{\text{gal}} \times 9 \frac{\text{gal}}{\text{min}} \\ &= 72 \frac{\text{lbs}}{\text{min}} \end{aligned}$$

Water/antifreeze solution density = 8lbs/gal.



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Other buried utilities to map include lawn sprinkler and irrigation systems, footing and leader drains, invisible fencing, and electric lines to outdoor lights or motion detectors. Consider line rerouting and splicing of interferences where feasible.

The economical target (as explained in the Soils Section of this course) is to install the Loop 6' -7' deep. This increases the chance of being in a fluctuating groundwater level. These are workable, but personnel cannot enter a trench deeper than 5' per OSHA 1926.651/1926.652 without the installation of a protective system. Normally, there is no need to enter the trench; contractors can unroll loop pipe from above. Digging 8' or deeper is preferred but could cause cave-ins. Bringing such a deep trench within the spring line of a mature tree jeopardizes its root system, so it is important to keep away from trees, as shown in figure 6.



**Figure 6 See how trenching avoids the roots of a mature tree.**

The essential building owner interview can clarify future property uses that may impact the project. For instance, in-ground swimming pools cannot go above a 6' deep loop. Also, garage and out-building footings require special attention and are discouraged from existing within the dedicated loop field area.



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Excavating under sidewalks and asphalt is a discouraged practice. Proposed paved parking lots drain away useful ground water and could impose heavy bearing loads on the Loop. Proposed parking lots with higher albedo solar reflectivity may be better suited to geothermal systems in southern states that require more cooling capacity. But, parking lot construction utilizes vibratory compaction while trench backfill does not, thus creating settling problems. In fact, 95% Proctor compaction could damage the Loop by striking any neighboring stones below. Also, backfilling Loop trench air voids with dry sand reduces thermal conductivity.

A vegetable garden with shallow fence posts and playing fields above a Loop would be fine. However, allowing intense root penetration by reforestation over a Loop field is not prudent. But unlike drainage perforated pipe that a willow tree root could plug, the heavy-duty Loop pipe cannot be penetrated by small roots. 2' to 3' deep road curbs are acceptable above a loop.

A 4" diameter PVC footing or leader drain pipe need not be an obstacle, since it can be exposed and saw cut. Follow this by digging the trench below it and installing the Loop. Complete the job with proper backfill and compaction. To deal with the severed PVC line, add Styrofoam insulation below the 4" PVC pipes and use two rubber Furnco couplings for each line to reconnect. If wholly contained in the removed topsoil layer, shallow footing or leader drains can become an obstacle, so check inverts. At the building foundation where the Loop enters and exits, install Styrofoam or other insulation to protect the crushed stone footing drain below.



**Figure 7 Footing drain space with Loop below and pink foam board insulation. Note that the worker only enters the < 5ft. deep trench after it is partially backfilled.**

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Another map planning issue is proximity to wetlands. Zoning Codes generally allow buried utilities up to the property line. Historic Districts are not architecturally affected if the heat pump is weather protected inside. Some Federal grant money does require verification that the ground loop will not excavate sensitive land, such as American Indian archaeological sites. The one or two-day disturbance to the ground within a Wetlands Buffer or "Upland Review Area" could require an Inland Wetlands Permit.



**Figure 8 Silt fence erosion control.**

Installing a Geothermal Loop in ponds or wetlands is beyond the scope of this course, as is the filtration needed for open loop “pump and dump” water sources. But for the Upland Review Area Buffer, Wetlands Boards have favorably permitted geothermal closed loop systems. They have the right to know that backfill will be insitu material only, and not a free draining cover that would alter ground flow patterns. Specify an erosion control silt fence (fig. 8) to protect wetlands and watercourses, and submit an Erosion and Sedimentation Control Plan that shows sequencing and notes. The thermal changes to the lawn should have basically no impact to vegetation and wildlife. Because the Loop is filled only with water and in northern climes, 15% to 20%± biodegradable Propylene Glycol antifreeze to allow flow at 22°F to 18°F, any unfortunate breaking of the Loop will not cause petroleum-based antifreeze to contaminate the wetlands or groundwater. Environmental regulators prefer this failsafe approach.

With a 50 year minimum guarantee and a 160-psi rating, the HDPE closed Loop can withstand sledge hammer pounding and careful backfilling with small rocks. But freeze bursting



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plain water will ruin a loop field. Propylene Glycol (PG) is still the industry standard, and potassium acetate is acceptable. Where this environmental issue is not a concern, check methanol (windshield wiper fluid) for better performance at low temperature viscosity or local codes for other acceptable antifreezes. As a cautionary note, the inside HVAC contractor that supplies the PG should never mix it with Methanol or other antifreezes.

### 3 Soils and Excavation

Figure 9 shows average ground temperatures that are similar to average annual air temperatures.

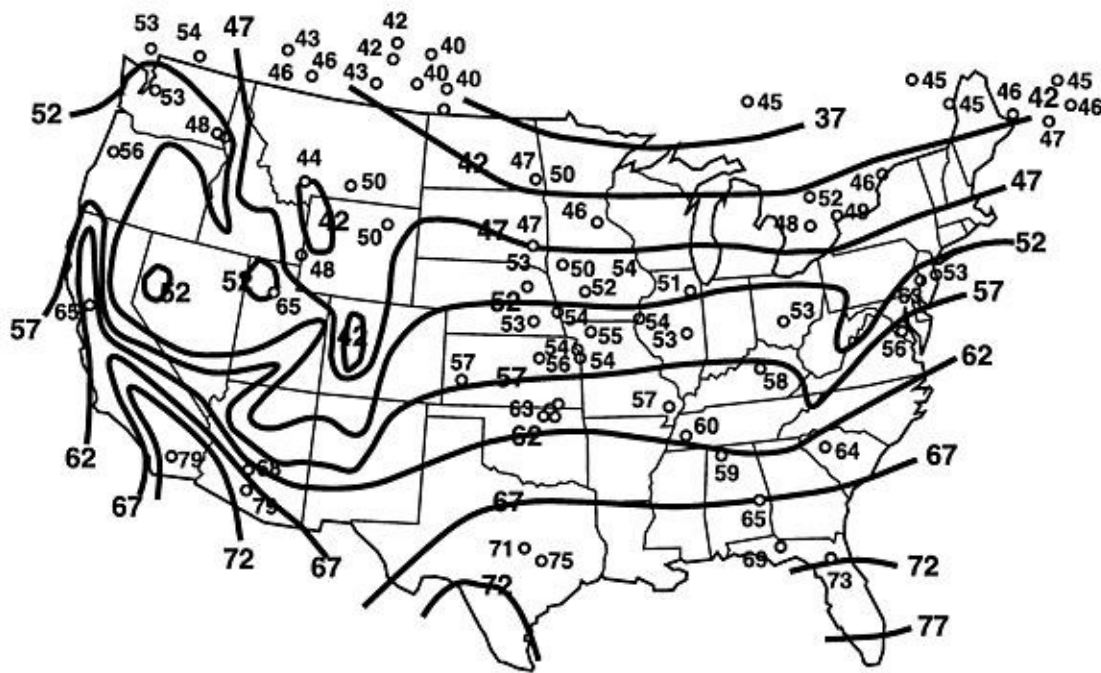


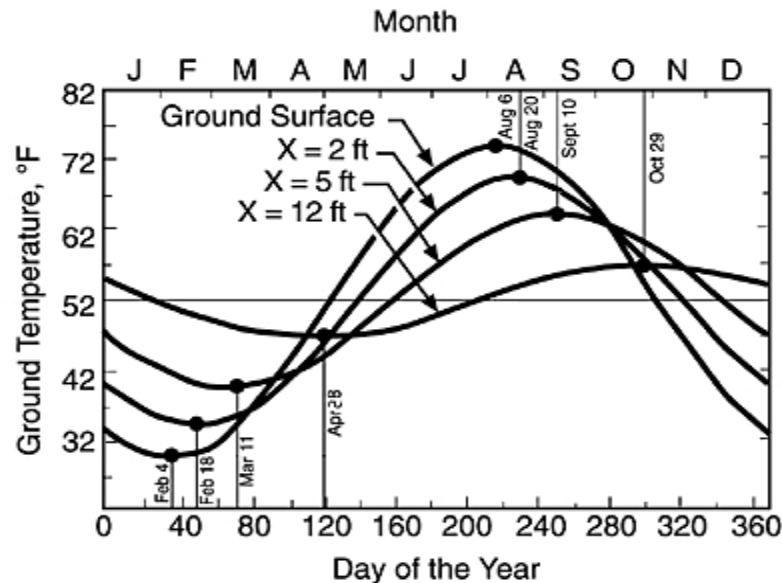
Figure 9 Contours of average ground temperatures.

Figure 10 shows that the deeper one goes, the more stable the temperature throughout the year. An economical depth is 6'-7'. This is not much less efficient than a 300' deep well, even with good thermal ledge rock. But a shallow 2' deep trench near frost level or baked earth fluctuates too much, as shown. We can adjust values for the geographic region away from that of the 52°F NYC average used in the graph below. For Oklahoma, the 52°F line should be

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adjusted to contour line 62°F to estimate temperatures there as a function of depth and season. 62°F average would have 42°F and 52°F below and 72°F, 82°F & 92°F on the axis above.

Geothermal software design programs have this information for the entire U.S. in their databases.



**Figure 10 Underground temperature changes by season and depth for a 52°F-map contour average.**

The engineer and construction professional is used to assessing soils for their load bearing capacity, permeability and thermal characteristics. On-line research can give the coefficient of Thermal Conductivity (K) and advanced design addresses Thermal Diffusivity, which is not covered here. To simplify for geothermal design, use the values in Table 1.

**Table 1 Soil Thermal Conductivities**

Soil Type	K in BTU/ hr. Ft. Deg. F.
Wet Sand	1.4
Wet Silty Clay	1.0
Dry Sand or Dry Silty Clay	0.5
Dry Clay that could shrink away from the Loop	0.2

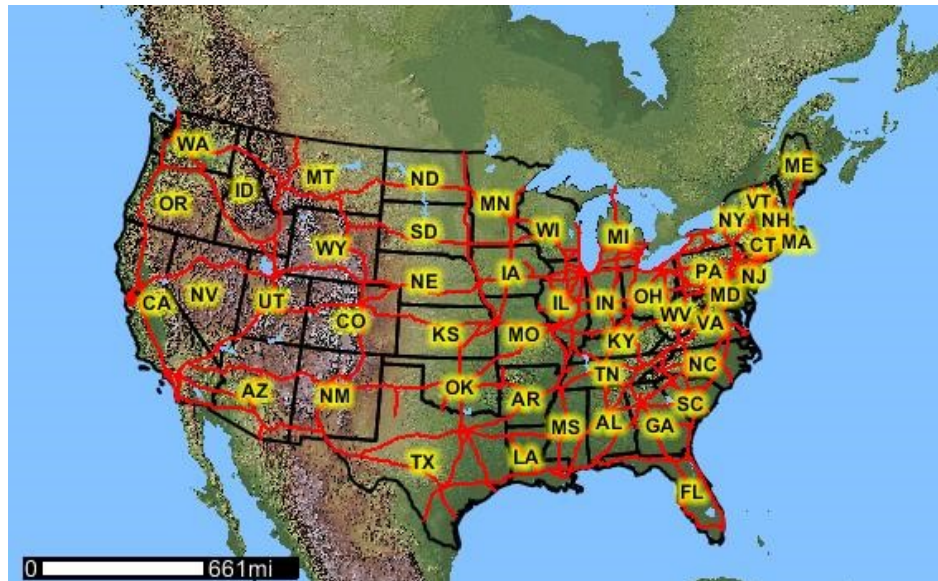
Experienced builders deplore groundwater as a general nuisance for bearing, slope stability and drainage. But water conducts heat 20 times better than air, so a Loop surrounded by

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saturated soil allows faster and more extensive thermal exchange, than it would if it were in dry sand with air voids that act like insulators. Some systems have added water drip sprinklers to keep the soil moist for better performance. The early design process should address that added expense and resource use.

Today's savvy designer, who used to refer to the Soil Survey Maps for the municipality, now goes on line to find this information (figure 11)

Enter the street and city address and delineate by cropping the desired Area of Interest (AOI). At the Soils Map tab above, receive a description of the soils type, and one can note in particular the horizon at a 6'-7' depth. Once the AOI has been delineated, go to the tab above it for soils maps. The soil and moisture descriptions are descriptive, but Thermal Conductivity properties are not given. Assign TC values after determining soil characteristics.



**Figure 11 Web soil survey, home page starting map.**  
<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>

*Website links are not required for test question answering.*

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## Trench Loop Types

The simplest design specifies a single Loop in Series in a trench to maximize heat and coolness extraction from the earth. This is the historically traditional design, which has since evolved to multiple pipes side by side, above each other, slinky coils, and parallel loops connecting to a manifold. Generally, in these advanced designs, shortening the trench length requires lengthening the Loop pipe length. Where excavating is costly, consider spending more on 2 or more pipes that share a trench, and draw on the same heat or coolness source. If land is limited and a large excavator is easily used, for advanced design, consider a slinky trench by purchasing more Loop for installation in the wider trench. Certified IGSHPA installers use their Slinky Installation Guide. But do not strain the available heat or coolness within a specified volume of soil. The soil's energy should last through a heating or cooling season, but will not if the Loop is compressed into too short of a trench.

Just as there are many ways to treat sewage effluent in trap rock, concrete or plastic chambers, there are many ways to draw heat and coolness from the earth. For good soils and a good excavating contractor, the single Loop can be installed without needing a certified heat fusion technician. Therefore, this time-honored procedure is suggested for beginning installations.

A ledge rock at 6' depth is a concern because sharp protrusions could cut into the Loop skin and reduce its useful life, especially in the smaller 3/4" diameter and other less expensive Loop sizes. In such a case, design a slightly less efficient 5' deep trench, or abandon the design. Large boulders can be left in place. If a short length of a 1000' long Loop can only be 3' deep instead of 6' deep, the difference is inconsequential and the loss in electrical efficiency is not a concern. But always attempt to avoid the frost or hot sun zone down to  $\pm 4'$ . A good designer will understand the excavation operation ahead of time, and plan accordingly. Similarly, borehole system loops running through a horizontal trench to a building should be 5', not 4' deep, and OSHA safe. There is no reason for people to be in deeper trenches.

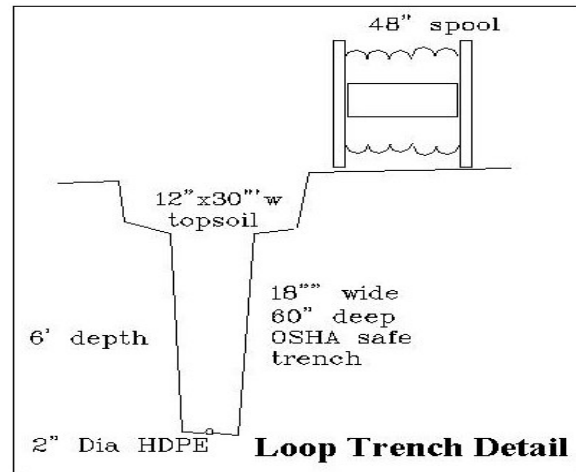
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**Figure 12** 2in. diameter single HDPE loop pipe is unwound from 4ft. wide spools and installed by excavators.

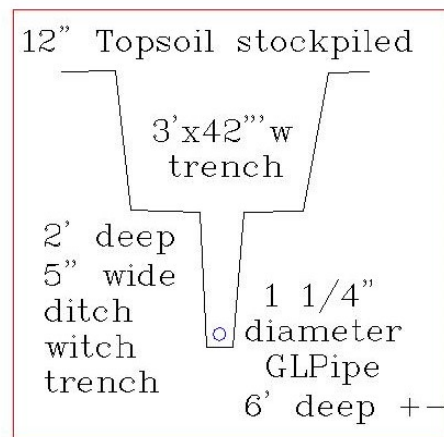
In general, there is no reason to enter a trench where the loop is being laid on its floor. However, when digging through collapsing saturated sand or hardpan, the excavating contractor should use good judgment and not double machine time in an effort to get a little deeper. The Occupational Safety and Health Administration ([www.OSHA.gov](http://www.OSHA.gov)) prohibits workers from entering deep trenches for their safety. Trenches deeper than 5' must be shore supported, shielded or sloped before entering. Furthermore, the material & spoil load must be kept 2' away. Avoiding the shoring requirement is appropriate for the budget conscious Loop installer. If desired because of excessive sharp rocks or to place the Loop in trench turns, use a ladder and a safe detail, like below. This operation should be supervised by a competent person that is familiar with OSHA trenching and excavation regulations.

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**Figure 13 Loop trench detail showing OSHA trench requirements for a 6ft. deep trench.**

Another option is to doze or dig out a one foot thick layer of topsoil to one side, then excavate a 5' deep trench to 6' below original and final grade (fig. 13). Without damaging the Loop, the laborer can shovel some cover to hold it in place. As the excavator operator digs out a nearby portion of the trench, he can also backfill the previous trench opening at the same time. Sometimes, a foot of cover is carefully machine placed and then saturated using a garden hose to ensure good compaction around the Loop. Tracer tape above the Loop may or may not be added, if the system is mapped. Tax Assessors can note GSHP improvements, but are generally prohibited from taxing the residence more because of its increased value.



**Figure 14 Combined excavator/trencher cross section.**



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**Figure 15 Heavy duty Minnesota agricultural chain trencher.**

Agricultural equipment may be suitable, if available. But only heavy duty trenchers can dig through boulders, and 5' is a deep cut in most dense soils. Digging a 42" wide by 3' deep trench with a large hydraulic excavator and then using a chain trencher or Ditch Witch to trench 3' deeper is also feasible (figs. 15 & 16). Backhoe contractors without trenching equipment can find them readily at local equipment rental establishments.



**Figure 14 3ft. Ditch Witch utility trencher, 3ft. deep range, for rent.**

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**Figure 15 A 4 in. wide Ditch Witch trench at the bottom of a 5 ft. deep excavated OSHA trench.**

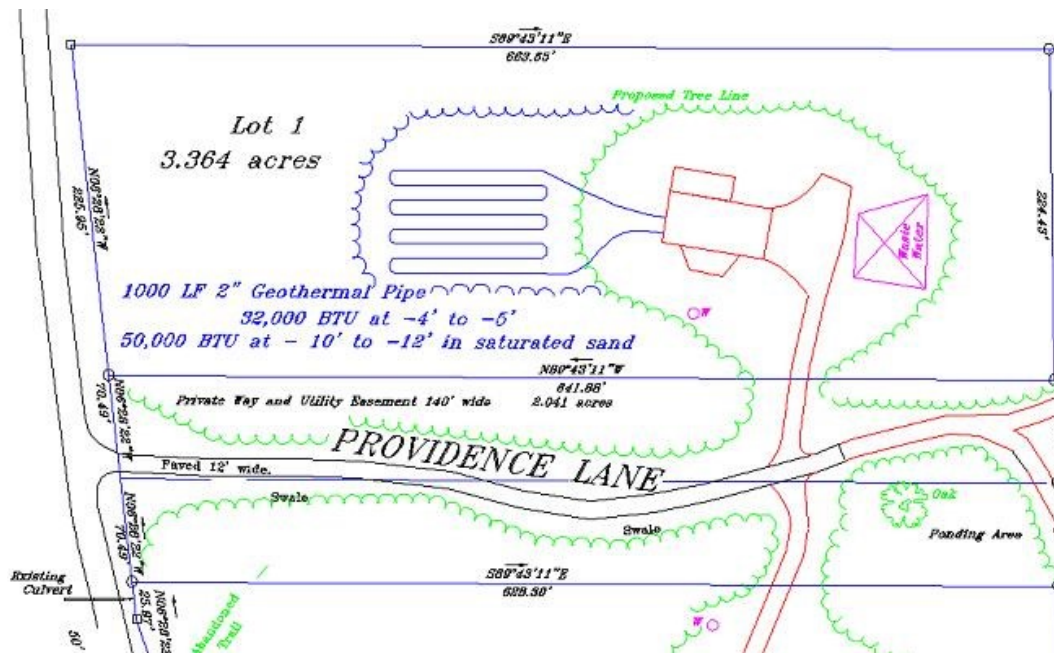
If cost is a major factor, removal of the topsoil can be avoided, especially in a meadow. However, mixing substrata with topsoil will result in turf re-growth that will show the trench location for years if additional topsoil is not added. The recommended hydraulic excavator choice is one outfitted with a narrow bucket and swing rotation hitch that will minimize soil removal from too wide a trench, although there is no harm in digging a 3' wide trench for a 1" or 2" diameter Loop.

From the Geo forum web site, <http://www.geoexchange.org/>, the installer of this system (fig. 18) felt that too much earth had to be moved to lay out the Loop. To avoid this situation, trenches are recommended, unless the soil is sandy and can be easily dozed.

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**Figure 16 Complete dirt removal versus trenching.** (<http://www.geoexchange.org/>)



**Figure 17 Mapping of Florida location with sandy soil for loop installation.**



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In deep Florida where the soil is sandy and trench sides won't be stable, the contractor should doze to a 12' depth for heavy AC use, if the residence is not a large user of heat energy. Check soil moisture at that depth and consider adding irrigation or drip lines to improve heat transfer.

In summary, determine the type of soil by the NRCS web site or by analyzing previously dug deep holes (new test holes may be cost prohibitive), select a good Thermal Conductivity Value to determine total length required, and plan a way to efficiently bury the Loop.

## 4. Length of the Loop

For a large commercial building, there are formulae and calculations to determine the required lengths of Loop. As in any engineering project, more design time is warranted for a larger scale construction. For a nominal fee, Geo-Connections, Inc in South Dakota (<http://www.geoconnectionsinc.com/>), who work in conjunction with the IGSHPA, will run a computer design based on input. Other alternatives are to download GeoAnalyst for \$50 per year or ask a heat pump manufacturer for their software. Where rebates are involved, calculate more exactly.

For an existing building retrofit where cost is a major factor, "Rules of Thumb" can be followed. Just as septic system designers refer to a table to convert percolation test rates to lengths of leaching trenches, so too can thermal properties of soil be simplified. For example, Architects and Structural Engineers do not calculate whether lumber wall partitions should be 2x4 or 2x4½. Instead, Industry Standards are referenced to save time and effort. There is not a simplified, universally recognized table for determining soil thermal properties, and the number of available resources is large. For instance, Virginia Tech recommends lengths of 100' to 400' of pipe loop per ton of refrigeration. Another standards group, The 1988 IGSHPA Installation Guide (<http://www.igshpa.okstate.edu/>), says to use 350'-500' of pipe loop per ton of refrigeration for a single pipe buried 4'-6' deep. Newer trench length formulae rely on parallel fusion designs by fusion certified people only. Well drillers encourage boreholes, not simplified competitive trench formulae, and they often use a standard 150' of pipe loop per ton in average rock.

For heating a 2000 square foot, 1½ story structure with good insulation served by a 3 ton (36,000 BTU's per hr. heat pump, providing 28,000 BTUs/hr. heating capacity at 32°F entering water temperature), specify a single Loop in a trench at 6'-7' deep according to Table 2.

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**Table 2 Recommended pipe and trench lengths.**

Soil Type	1 1/4" dia. Loop	2" dia. Loop
Wet Sand (K = 1.4)	1000'	800'
Wet Silty Clay (K = 1.0)	1050'	850'
Dry Sand or Dry Silty Clay (K = 0.5)	1250'	1000'

For heating applications north of the 52°F-ground temperature contour from New York and west, add a little more length; subtract length for more southern climes. If an owner wants less capital investment in the Loop by using less material, thus gaining a slightly higher cost in monthly electric bills, then that is fine. Retrofits usually have an existing backup heat source for very frigid days. To calculate more exactly, use software or the formula from the old or new IGSHPA Installation Guide:

$$LH = CAP_H \frac{\{(COP_H - 1)/COP_H\} \times (RP + RS + FH)}{(T_L - T_{MIN})}$$

(The worksheet can also be used.)

Or,

$$Length = \frac{Heating\ Capacity \times Coef.\ of\ Performance \times Soil\ Resistance\ factors}{Temps.}$$

The Guide continues on page 100: *"The designer has a wide range of choices in the length of the ground heat exchanger."*

When choosing between Loop sizes, consider the advantages and disadvantages:

For example:

- A Large 2" size Loop stores more water and PG or methanol antifreeze, so contact time with the earth is increased before the heat pump reuses the solution.
- For 1000' of 2" Loop supplying a heat pump using 8 gallons per minute, the fluid volume is 150 gallons, (120 potable water, and 30-gals PG) and the routing time is 19 minutes.
- Flow must be Turbulent (See IGSHPA manual.)
- Inside diameter is 1.36", and weight is 300 pounds for 1000'.
- \$2.00 per foot for the 2" Loop

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- For a smaller building of perhaps 1,000 sf, a 1½ or 2-ton heat pump will circulate the exchange fluid rapidly, even at 3 gals/ton, so favor the larger pipe diameters.

Or:

- For 1¼" there are 75 gallons circulating in 9 minutes.
- Twin 1¼" in a 24" wide bucket trench works, too.
- Figure a cost of \$1.00 per foot for 1¼"

¾" and 1" Loop are much less expensive, but are mostly used for parallel and slinky systems. Fusion to the buried manifold is done by certified fusers only. A fusion machine and heater can cost \$500-1000 for socket fusion and \$2500 for butt fusion; they can also be rented. Because small pipes can kink due to their thinner skin, they should be left to the certified installers for installation. 1½" diameter Loop is also available and its length should be prorated if the local supplier price is good. Sizes over 2" are uncommon for small residential and commercial trenches. (Slow flow might be laminar.)



**Figure 18 2in. HDPE loop material labeled 'Thermal' under a 1.25in. loop with a butt fused joint. Both rest against a 5-Gal. bottle of propylene glycol.**

By logic, the longer the heat transfer fluid remains in the ground, the more heat it will absorb. So, if the heat pump is receiving fluid at 40°F and returning it to the ground at 35°F, the longer the Heat Transfer Fluid can absorb ground heat before being reused, the better. On cold days, expect the incoming water temperature to drop as the heat pump harvests the energy. See



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typical temperatures at [www.groundenergysupport.com](http://www.groundenergysupport.com) or [www.buffalogeothermalheating.com](http://www.buffalogeothermalheating.com)  
COP is higher for higher Loop water temperatures.

In general, two-stage heat pumps in air conditioning mode can supply more BTU draw than in heating mode. So, northern state systems using the prescribed lengths are over-designed for cooling, and southern states that need minimal heat and maximum cooling will be over-designed for heating. Therefore, adjust lengths accordingly or calculate with worksheets and trusted software to obtain specific lengths. Having extra length is not bad, if the cost is acceptable. Don't be a Short Looper!

For initial installations, skipping the hot water feature is recommended. But for those interested in the optional domestic hot water heat systems, add on a desuperheater. Obviously during the air conditioning season, hot water generation is efficient, but during heating season, the Loop capacity is stressed more, and length needs to be increased perhaps by 10%. Desuperheaters generally preheat water in a buffer tank from about 50°F to 90°F before final heating to 125°F degrees or so in a gas, oil or electrically heated tank. Swimming pools are not generally heated by geothermal. Never run pool water through a geothermal heat pump, but use a heat exchanger instead if attempted. Rebate programs do not reimburse for swimming pool geothermal heating. Sidewalk and pavement geothermal heating is also done to save fossil fuels, but is not common.

## Interior Flow Center Circulating Pump effect on Loop

Loop water (and antifreeze in the north, generally not used south of North Carolina) must be supplied to the heat pump at about 3 gallons per minute per nominal ton. This is under the inside contractor's jurisdiction (approximate cost of \$700). Pump head charts are examined in the heat pump course because they are of interest to engineering designers. The outside Loop skin friction and resulting head loss is less for a 2" Loop than for a 1¼" Loop. The loss could be 5' of head for every 1000' of Loop length depending on the gallons per minute flow. The system designer naturally wants to minimize perpetual pumping costs. Some minimization is prudent, but the flow pump might use one amp of power compared to 12 amps for the heat pump compressor. Design the Loop pipe knowing that circulating cost is minimal compared to the compressor.

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**Figure 19 Under assembly: 2 in. loop inlet with blue cap, 2.5-ton split heat pump. The flow controller Grundfos pump is wall mounted. HVAC contractor will complete connections once the loop outlet is pushed through the second drill hole. Electric power whip, upper left.**



**Figure 20 In this alternative flow control center, a non-pressurized canister circulates loop water and PG to the heat pump at about 3-5 psi.**

From a piezometric analysis, a full Loop will balance head loss so that it does not matter how deep it is buried. Unlike a well pump drawing head from a 200' or so depth, a full Loop balances head inlet and outlet pressure. Only skin friction loss must be determined by the indoor

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HVAC professional selecting the Flow Controller Circulating Pump, usually from the manufacturer's Guide Book. Of course, there cannot be air inside the loop or the piezometric assumption is invalid. Plus, air can cavitate pumps. Not needing to know the depths and elevations for a fully filled Loop means that the topographical contours the engineer and surveyor are used to working with are not required for horizontal geothermal trench work, except for erosion control.

## 5. Design Loads and Related Interior Heat Pump Work

### *INTERIOR WORK: DESIGN LOADS*

#### *Building square footage and Insulation. BTU / hour loss.*

After the capacity of the land and soils has been deemed suitable, examine the building to be served for its energy requirements. Then, refine the actual required Loop length based on heat pump tonnage. If the architect has this tonnage for newer buildings, design from there. Where no information is available, heat loss can be calculated using ACCA J on-line software. Or, ask the inside contractor to size from the heat pump based on similarly sized and insulated buildings. If the HVAC contractor feels that the existing systems were oversized, as AC units often are, a new Heat Pump tonnage can be selected, but remember that heating loads usually exceed AC loads in the north. Finally, determine Heating and Cooling **Capacity** tonnage, not Nominal tonnage.

Before any building owner retrofits all or part of their heating and cooling system to Geothermal (the system that over a million American houses have), they should be sure to seal all air infiltration cracks and leaks first. Also, check the attic insulation to ensure that it is as thick as is feasible. Energy efficient window replacement or storm windows and doors need to be considered as part of the plan. See SUNCAM course 055 about Home Energy use.

## Geothermal Heating and Cooling



**Figure 21 Retrofit split air handler and ductwork with heat pump refrigerant in black insulated copper line.**



**Figure 22 New home unit heat pump with compressor on bottom and air handler on top.**

Buildings with existing duct work and air handlers in place are best suited to a geothermal retrofit. Fossil fuel systems can provide heat to the coil in the air handler at about 140 degrees. Heat pumps efficiently heat to 110°F or 120°F maximum resulting in more air being circulated.

## Geothermal Heating and Cooling

The electric power portion for air handlers is minimal (about 1 amp), and indoor air quality is enhanced by blowing more 110°F air rather than less 140°F air. Some advances are being made to increase temperatures beyond 120°F.

For a baseboard heat system, radiators that were sized for a 140°F source may be inadequate on very cold days. There are water-to-water heat pumps that supply baseboard hot water or radiant heat piping under floors, but forced hot air is most common. Be sure that retrofit radiators are not corroded, which could lead to heat pump heat exchanger problems. For buildings without duct work, consider a ductless system (fig. 25) or console that combines all three functions: heat pump, circulating flow controller pump, and air handler.

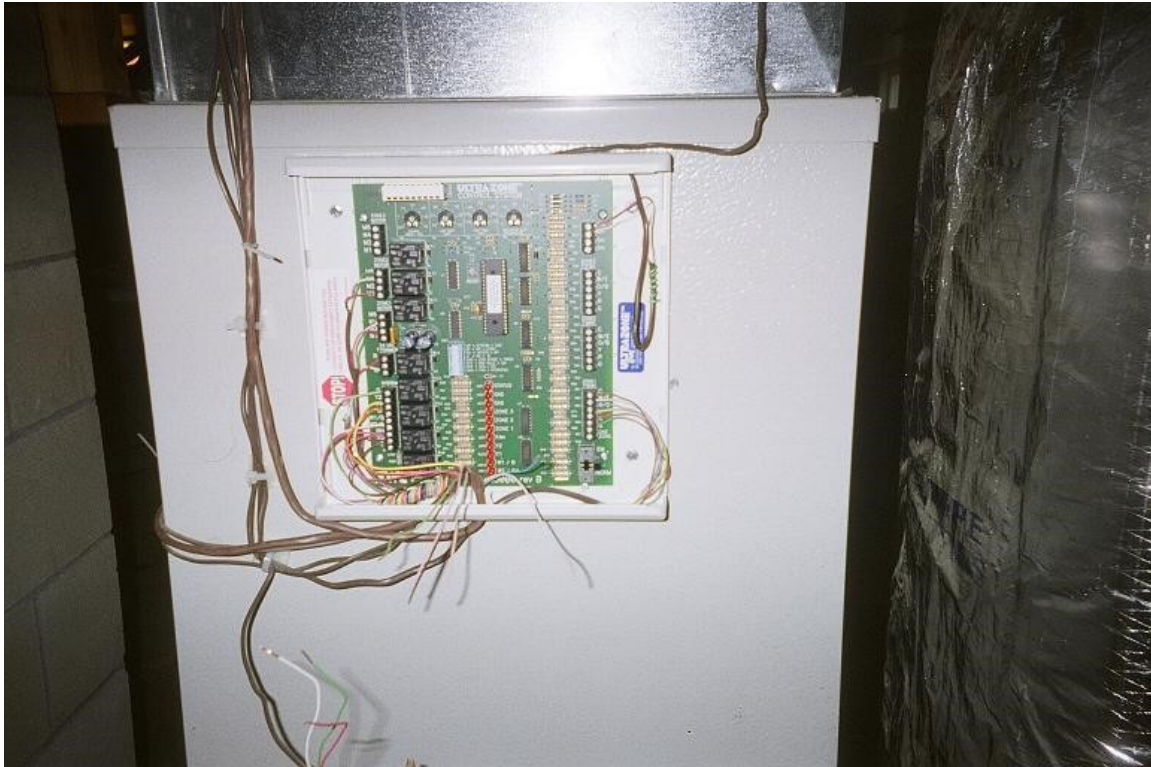


**Figure 23 Ductless console by ClimateMaster as shown, or Carrier, or WaterFurnace, etc.**

An entire building need not be all geothermal. The benefit of retrofitting is that the geothermal system can be sized for a single in-place system. For example, a 4,000 square foot structure has two 2½ ton air conditioner zones, supplying 30,000 BTU/hr. cooling or 24,000 BTU/hr. heat each. There may only be a need for a 2½ ton heat pump to service one zone. The second zone would still be served by the fossil fuel system that remains in place doing half of its previous work with increased life span and less wear and tear. Saving the cost of connecting to attic ducts by using the less expensive basement ducts might be prudent. Another item of interest on the inside of the building, but not Loop related, is the low voltage electrical control of the system.



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**Figure 24 Programmable circuit board from thermostat - mounted on the air handler.**

In the retrofit, the existing system can be electronically programmed by the circuit board attached to the air handler (fig. 26), to provide backup heat if temperatures sink during a cold snap and the geothermal heat pump cannot keep up. Sensors could shut it off if the incoming fluid temperature drops below 30°F (still in circulation because of the antifreeze Propylene Glycol.) Similarly, it can be programmed to shut off if the heat pump cannot satisfy thermostat needs within 15 minutes. This is a safety backup, but many satisfied geothermal system owners report that they have never had to use their backup. For new construction, keep backup system cost minimized by having (inefficient) electric auxiliary strips within the cabinet or plug-in space heaters available. This will save the cost of chimneys, fuel oil tanks, gas lines, etc.

The homeowner managing the project should be sure that both the inside HVAC contractor and the outside engineer/excavating contractor coordinate their planning. During preliminary planning, duct work and zone issues need to be resolved along with soils and land-use issues. An active and prepared owner will not have future maintenance questions for the



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designer beyond the equipment manuals. Outside maintenance is virtually nonexistent once the lawn or meadow regrows. Inside maintenance for the HVAC contractor could involve follow-up to verify that the initial purging was successful and no air is trapped in the Loop. Duct filters must be replaced by the homeowner.

## 6. Retrofit Coring into the Building

The standard is that outside buried Loop must be continuous or, if in sections, heat fused to 400 or 500°F. The inside Loop can be connected conventionally at the discretion of the plumber or HVAC contractor. Outside Loops enter through the concrete wall and are capped off until used by the HVAC contractor.

For new construction, the contractor can cast concrete walls with sleeves for future Loop installation. For retrofit jobs where the Loop enters from the soil, one must drill through the concrete or block material or expose the Loop to the air and drill through the wood frame. Lifting an insulated Loop into the atmosphere is feasible, but inefficient, especially during zero degree days. Heating or cooling losses can mount if the heat pump is located outside, so an indoor heat pump on a noise deadening pad should be considered. Fortunately, it will be quieter than the air handler or old boiler/furnace noise.



**Figure 27** Dry drilling that creates concrete dust.



**Figure 28** Wet drilling with drill attached to wall by suction.

## Geothermal Heating and Cooling

If dry drilling from the inside, be sure to build a plastic dust tent (fig. 27) and wear a face mask for protection. Concrete dust will fill the entire basement, garage or utility room if this step is skipped. A building owner will be justifiably unhappy with a contractor or engineer that contaminates an entire level because of poor safeguarding. Even when drilling from the outside trench, the inside should be blocked to prevent concrete dust from traveling during the final drilling moments.

Dry drill and bit rental should be budgeted \$70 since conventional drills are undersized. If a little water can be tolerated on a basement floor, a wet drill requiring a garden hose attachment rents for \$120 with a carbide bit. A 3 ¾" bit cannot be used if Link Seals are sized for a 4" bitted core. Drilling through a 4" thick concrete floor slab is also feasible but presents structural backfill problems associated with undermining the footing.



**Figure 29 To drill through an existing concrete or block foundation wall, select a drill bit that is correctly sized for the outside loop diameter and the Link Seals that will be used to waterproof everything. Pictured here, six Link Seal bolts for 2in. HDPE loop tightened by ratchet and core with pink insulation to the left.**

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If drilling from the outside after a backhoe (not trencher) has exposed the foundation wall, be sure the inlet and outlet Loops are spaced apart so that they do not influence each other with frost or heat generation. Measure and spray paint entry marks where drilling will occur so that inside job results are neat and accurate. Consider the interior piping that should not cross doorways, etc. Be sure the Loops are separated from the corners and the floor so that hookups can be made. The lawn outside should not be under an inaccessible deck or immovable patio.



**Figure 30 Inlet and outlet loop insertions into basement.**

Three of four loops enter a basement, only 4' deep, but 6" above slab level.

Blue insulation foam board is placed above footing drains.

Black tar seals original tar where excavator bucket scraped it.

The 900' long return end of the leftmost loop must be dug and inserted.

Even with modern rubber wall foundation waterproofing and a good polyethylene and tar water proofing in place, a breach to insert the two or more Loops can lead to leakage in the basement or up through a slab. Though readily available, spray foams are inadequate waterproofing ingredients. Properly applied hydraulic cement from the outside to stuff an oversized core (and sleeve) will prevent leaks and is good with a tar coating because hydraulic cement can shrink with the large temperature swings. And, as an added measure, it assures that no radon or insects can enter the building through the tightly closed Loop. Do not underestimate the importance of proper waterproofing from the outside. Backfilling stresses must not deform the hydraulic cement plug seal. Repairing this mistake later from the inside will be difficult, if not impossible. Creating a surface drain after the fact is imprudent as is digging near completed



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Loops, putting them at risk for nicks. This would give the 50-year warranty a weak link. There should be no loose portions of the Loop except inside. Rubbing against concrete, caused by circulation vibrations of the water and PG solution, could add fatigue to the Loop.

Once the Loop ends have entered the building, they can be air or water pressure tested when the water and PG solution have been pumped into it, usually by the heat pump installer. If that operation is separate, the excavating contractor and engineer may choose to air test to about 40 or 50 psi to be sure the Loop was not damaged during the burial process. Standard commercial tests to 100 psi might be excessive.



**Figure 31 Working split unit heat pump with flow center accessing loop inlet and outlet. A short reserve loop installed 24in. above the slab was not necessary. The line to the ceiling is insulated copper carrying refrigerant to the air handler.**

## Geothermal Heating and Cooling

### **Electric usage demonstration of a ground source heat pump.**

*Moving heat not making it.*

For a reality check on the Coefficient of Performance of a ground source heat pump, the 2.5-ton heat pump and flow center shown in fig. 31 is drawing 2694 watts to heat 1980 sq. ft. in February, as read by the Wattmeter to the right of the panel box.

By comparison, the small 8" x 9 1/2" space heater with 6" fan is plugged into a Kill-a-watt meter (fig. 32). Note that it reads 1403 watts. COP 1 electric heating is just so wasteful.



**Figure 32 Small space heater with Kill-a-watt meter.**



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## Final Grading and Landscaping

After the Loops are installed and inserted into the building, backfill and proper topsoil are applied. Trenches will settle and the first season might have more air trapped near the loops than later years when frost and seasonal rains consolidate the soil better. The project should budget to re-establish lawn areas or the landowner can plan to address them next year. Vibratory compaction near loops is discouraged since sharp rocks could scrape thinner walled loops. Instead, backfilling mounds for later settlement and compacting trenches from above will result in a level lawn or meadow area. Budget some time to add topsoil and seed next season and then enjoy the use of the resource forever hidden from view.



**Figure 33 Using weight to compact backfilled mounds in a loop field.**

# Geothermal Heating and Cooling

## 7. National Topics

The U.S. Green Buildings Council at [www.usgbc.org](http://www.usgbc.org) runs Leadership in Energy and Environmental Design (LEED) for Homes. This addresses Ground Source Heat Pumps in Table 19 a & b with Energy and Atmosphere EA6 credit for EER at 14.1 for their conversion factors, and COP at 3.3 on page 67 of the Home Reference Guide. For the larger New Building and Major Renovation Rating System, LEED credit EA@ notes that GSHP systems are not in the same category as renewable deep earth Hot Steam Geothermal Sources. But GSHP's are eligible for credit under Optimized Energy Performance and for Prerequisite Minimum Energy Performance.

The American Recovery and Reinvestment Act of 2009, enacted February 17, 2009 offers homeowners a 30% tax credit for GSHP systems, and removes the old \$2000 maximum tax credit cap. This covered the period January 1, 2009 to December 31, 2016. It lapsed for a year and was reinstated in February 2018. In 2021 the tax credit is 26%. These residential geothermal systems must meet Energy Star requirements. Businesses receive 10% tax credit and a generous depreciation allowance.

To learn more about ground source heating and cooling Federal incentives, rebates and policies, state by state visit [www.DsireUSA.org](http://www.DsireUSA.org). The Department of Energy had a useful cost comparison calculator showing ground source efficiency over alternative heating and cooling systems. [www.eia.doe.gov/neic/experts/heatcalc.xls](http://www.eia.doe.gov/neic/experts/heatcalc.xls) This is now Frequently Asked Questions.

### HEATING FUEL COMPARISON CALCULATOR categories

Fuel Type	Fuel Unit	Fuel Price Per Unit (dollars)	Fuel Heat Content Per Unit (Btu)	Fuel Price Per Million Btu (dollars)	Heating Appliance Type	Type of Efficiency Rating <sup>4</sup>	Efficiency Rating or Estimate <sup>5</sup>	Approx. Efficiency (%)	Fuel Cost Per Million Btu (dollars)
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While IGSHPA is dedicated to promoting geothermal standards and training, the Geothermal Exchange Organization ([www.geoexchange.org](http://www.geoexchange.org)) manages government policy at the national level. And GEO began administering IGSHPA in late 2020.

# Geothermal Heating and Cooling

## COURSE CONCLUSION

The sustainable design book *Cradle to Cradle* by McDonough & Braungart notes on page 31, that "the standard operating instruction seems to be 'If too hot or too cold, just add more fossil fuels.' when we should be paying "attention to harnessing and maximizing local natural energy flows."

With the cost of fuel always changing, the experienced construction professional knows that prices will not be low forever and that those who install their Ground Source Heat Pump systems now will reap the payback benefits in the future.

Those who pass this SUNCAM Course should be qualified to design and oversee construction of a small building's new or retrofit system. For design of larger commercial and complicated systems, pursue more on line studies and consider taking the three day IGSHPA workshop and test to become an accredited installer. Passing this SUNCAM course will give you knowledge beyond what other installer candidates will have. Those with three years of geo-experience and a professional engineer's license or more years of experience should sit for the geo-designer designation with IGSHPA and the Association of Energy Engineers.

Engineers and other professionals who can design and install these vital systems will make a difference in people's lives by saving them long term energy costs and reducing the pollution of our atmosphere.

