Geothermal Heat Pumps for Small Buildings

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Introduction

Geothermal Heat Pump information is widely available on the internet, but is often repetitive and consisting of the same basic scientific principles. This course uncovers the mystery, takes an in-depth look at features, and addresses the applied science of heat pumps supplemented by practical applications and sample photos that are useful to the professional engineer, contractor or design professional. It is used as part of a 12-hour college course on Ground Source Energy.

Geothermal Heat Pump systems save substantial operating costs compared to electric or fossil fuel methods. 'Water Source' or 'Geothermal' or 'Ground Source Heat Pumps' all refer to the same machine (WSHP's, GHPs or GSHPs). A **GSHP** provides an efficient way to move heat from the ground into a building or to move heat from a building into the ground. Of course, the 40 to 50 degree Fahrenheit ground heat is not harvested freely like a hot spring or deep earth heat source, instead it is amplified by using some electricity, though not as much as other less efficient systems. A simple analogy is the refrigerator that cools the inside while heating its outside coil.

A client may call a local HVAC contractor with geothermal credentials, who will provide the heat pump brand they regularly install. But other discerning customers will be interested in knowing more about the unit and will want to compare features, beyond seeking the most tonnage for the lowest price. For the design professional who specifies or installs a geothermal system for a small building, two separate components are involved:

1. The outside ground heat exchange (GHX or GHEX) loop discussed in the separate SUNCAM.com courses 029 and 91.
2. The inside heat pump and heat distribution system, which is the topic of this course.

GSHP units are classified as;

- Packaged (the size of a refrigerator with Gavelin or Stainless Steel cabinets that have higher warranty life).
- Split, as half-sized, to be connected with a copper refrigerant line set to a separate air handler.
- Combo for an air and hydronic unit.

Geothermal systems have several methods of execution and installation, although there are two general types:

1. Closed loop with water and antifreeze, such as biodegradable propylene glycol and methanol, etc.
2. Open loop that has three requirements:
    1. A reliable source of abundant water (thousands of gallons per day).
    2. An acceptable recipient water body, other than a sanitary sewer, or unapproved aquifer or well. In NY, discharge 1 million gals/yr. with a permit.
    3. Pure water that is contaminant free to minimize filtering, as specified. Scaling might require an annual maintenance contract to clean off with muriatic acid.

Another variation is an open loop with fresh and consistently warm 50°F water. This system can be 15% more energy efficient, however, the filtration and discharge issues are often overwhelming. The simpler systems rely on the closed loop with propylene glycol antifreeze solution. There are also Direct Exchange (DX) systems that are drilled at an angle by a track drill with copper tubing and refrigerant inside. These are more complicated systems that send the refrigerant directly through the ground and heat pump compressor and condenser. The GSHPs discussed here are the ones mostly used for small buildings, i.e. conventional closed loop GSHPs, although there are still other variations with merit.

The closed loops with biodegradable antifreeze in water solution are either horizontally trenched, bored or installed within vertical drilled wells. Programmable thermostats ('set and forget') allow all-in-one GSHPs to reverse the flow from heating during the winter to cooling in the summer. For loop field efficiency, adding heat back into the ground in the summer is prudent. For simplicity of instruction and for clarity, most of the operation theory in this course is explained for Heating Mode and can be simply reversed for Air Conditioning. Heat from the earth in winter becomes heat to the earth in summer. Heating in northern states becomes more economical when 600 to 800 gallons per year from a #2 diesel fuel oil system can be replaced with a 3-ton GSHP.

Figure 1 Package heat pump, compressor and heat exchanger below. Blower fan and blue condenser coil, coated to protect it from corrosion.

Most information about heat pumps is available on-line from the manufacturers themselves. Each company describes its own product without allowing the specifying engineer or designer to compare and decide which features are most important.

No brands are endorsed here, but examples (and those you may submit to www.SUNCAM.com for consideration that supplement knowledge in this course) are listed for the practical education of the professional design engineer, contractor or building inspector

Throughout this presentation, various website links are provided for the reader's knowledge and as footnotes, but they are not required reading for the test questions.

This course addresses these issues:

1. The encyclopedic definition of GSHPs, their history, and how they work. Photos and diagrams of the inner workings include:
   a. The compressor.
   b. The condenser at the air handler.
   c. The ground loop to refrigerant heat exchange coil.

2. Explanation of pertinent design parameters such as;
   a. The Coefficient of Performance.
   b. The Energy Efficiency Rating.
   c. BTU/hr. sizing.
   d. Refrigerant details, working temperatures, water flow, safety controls.

3. Introduction to the major manufacturers, distributors and dealers and associated trade organizations such as:
   a. AHRI - Air conditioning and Heating Refrigeration Institute, www.ahrinet.org
   b. ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, www.ASHRAE.org
   c. ACCA - Air Conditioning Contractors of America, www.ACCA.org
   d. IGSHPA (pronounced Iggspahh) - International Ground Source Heat Pump Association, www.IGSHPA.org
   e. GSHPC – Ground Source Heat Pump Consortium www.Geoexchange.org on line forum

4. Discussion of ancillary features like desuperheaters for domestic hot water generation and flow controller pumps, air handlers, flushing kits, a water to water GSHP, etc.

5. GSHPs in academia and assembly.

Heat Pump History and Contemporary Status

From the U.S. Department of Energy: http://www.zebralliance.com/docs/geothermal_report_12-08.pdf

GSHPs started in the 1950's using Florida groundwater or canal water. (Lord Kelvin's original concept preceded this in the mid 1800's.) In the 1960's, the closed loop was developed in California, and systems spread to the east coast where they were made to operate at greater temperature differentials in the 1970's and 80's. Approximately 60,000 GSHPs were installed each year thereafter, and 600,000+ units are still operational. This number increased dramatically in 2008 when oil reached $150 per barrel. Currently, at least 16 manufacturers produce small GSHPs for residential and small commercial uses. Major companies include: Climatemaster, Water Furnace International, Florida Heat Pump (Bosch), and Enertech (Geo Comfort, Hydron Module & TETCO Geothermal). McQuay International, Mammoth and other regional companies make GSHPs, too.

At the IGSHPA conferences, these and companies such as Bard, Geofinity, Geo Master, Geo Furnace, Ice Kube Systems, Trane, Rheem and Spectrum are also present. Carrier and others source brands from companies such as Bryant.

Other well-known manufacturers and suppliers include: Addison Products Co., Compax, Inc., Comfort-Aire (Century), Hydro Delta Corp., Hydro-Temp Corp., Millbrook Industries, and The Whalen Company.

At http://www.renewableenergyfocus.com/view/4759/us-shipments-of-geothermal-heat-pumps-surge-40/, the DOE report is updated to 2008 when energy prices spiked. At least 121,243 GSPs with a total capacity of 416,105 tons were produced that year by 23 manufacturers, earning $319 million in shipment revenues. Now, more than half are produced in Oklahoma and Indiana with 16% being exported outside the country, mostly to Canada. In general, assembly of components for American distribution is done in the United States.

Utilization is almost equal between residential and commercial. Foreign made GSHPs that use DC electric compressors should be checked for AC (Alternating Current) electrical service. Some rebates have Buy American provisions and Davis Bacon rate stipulations that should be considered during GSHP selection. The 30% federal tax credits for residential and 10% for commercial that lapsed in 2017, were reinstated by Congress in 2018, changed to 26% for 2020 to 2022 and 22% in 2023, for residential installations.

Figure 2 Lobby of Indiana's WaterFurnace showroom.

Figure 3 From the IGSHPA Exhibition Hall in Dallas before opening. A GSHP package unit with an air handler on the left and a split GSHP on the right.

GSHP System Process

Figure 4 Interior components of a Copeland dual stage compressor (compare to two gears in a car).

Compressor design is an important consideration when selecting a GSHP. Variable capacity units with three or more stages have been introduced for more efficiency, but the two-stage compressor has proven to be reliable and efficient. It has approximately 67% of capacity in Stage 1 and 100% of capacity in Stage 2. The conventional single stage compressor is less efficient, but saves capital cost (just over $3000 for a three-ton all-in-one GSHP). To address humidity in Air conditioning mode, Stage 1 of 2 can be prioritized, along with the air handler blower controls discussed later. Other terminology is part load and full load.

In Step 1, the compressor uses electric power to compress the refrigerant within the copper line set tubing. R-11 and R-12 refrigerants are no longer used in GSHPs because they deplete the ozone layer, and R-22 is being phased out. In fact, some major manufacturers have recently discontinued it. The refrigerant with about 6% more efficiency than R-22 is R-410A, also marketed as Puron, Genertron R-410A and/or AZ-20. R410-A operates at higher pressure (300 to 400psi) than R-22 and is safely handled only by trained and EPA certified technicians who understand the difference between the new and old equipment. Beyond this course, more information on R-410A can be found at this link: http://en.wikipedia.org/wiki/R-410A. R-410A is used for projects and design discussed in the course instruction.

In figure 5, the compressor is in the center of the diagram showing how heat is brought from the earth into the building depicting the Heat Mode used in winter time. The orange, red, cyan and blue colored lines show the R-410A changing temperature within the copper or copper and nickel sealed tubing. The yellow green colored line is the sealed water and antifreeze ground loop, similar in color to real propylene glycol and water antifreeze solution. The domestic hot water tank option shown in the diagram will be addressed later.

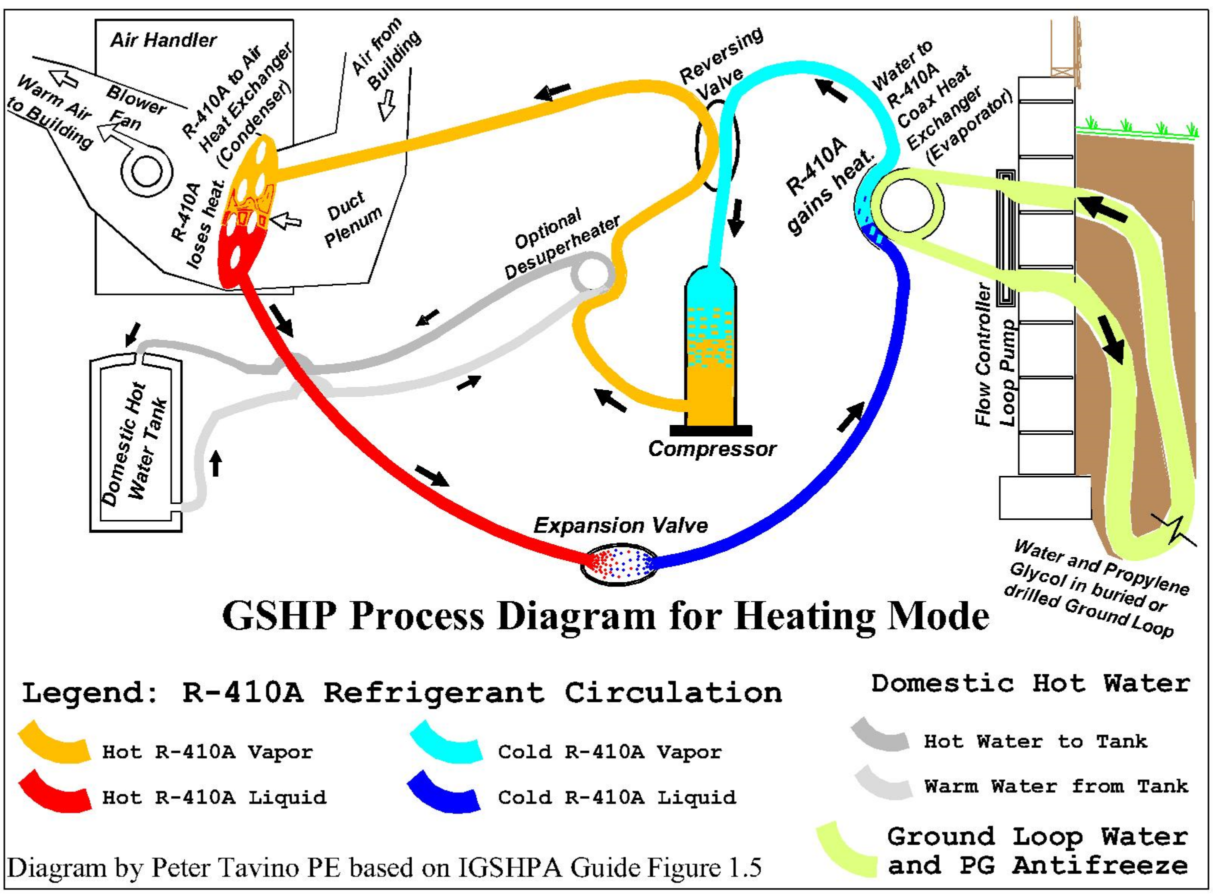


Figure 5 Heat Mode diagram. Similar to Figure 1.5 in the Closed-Loop GSHP Systems Original 1988 Installation Guide distributed by IGSHPA.

The compressor uses electricity to literally compress the R-410A and heats it up as hot vapor. Changes of phase in thermodynamics follow Gay-Lussac's Law, which states that when volume and mass are fixed there is a direct relationship between temperature (Kelvin units required) and pressure so that when gas molecules are compressed, temperature rises.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

The hot R-410A vapor, in its insulated copper tube line kit, passes through the cylindrical brass reversing valve (fig. 6) before it is sent to the condenser coil. In heating, flow is in one direction, then in cooling mode, the refrigerant reverses its circulation path so that the heat coil condenser becomes an evaporator, and the coaxial heat exchanger becomes a condenser.

Figure 6 Copper tube assembly going from brass reversing valve to the condenser coil.

The R-410A then flows to the air handler and duct system in a cabinet space that can be either separate from the heat pump for a Split GSHP, (especially in a retrofit) or the GSHP and blower fan can be in one larger cabinet package unit. The R-410A to air exchanger looks like a simple metal radiator with much of the copper or steel tubing exposed to air flow, thus providing an environment for the condensing process that produces heat.

The circular blower fan moves clean warm air across the condenser where the air is heated and then transported to the duct system and building interior. GSHPs in small buildings normally heat the R-410A to a maximum of 110°F. Figure 7 shows the approximate Pressure-Enthalpy graph for R-410A.

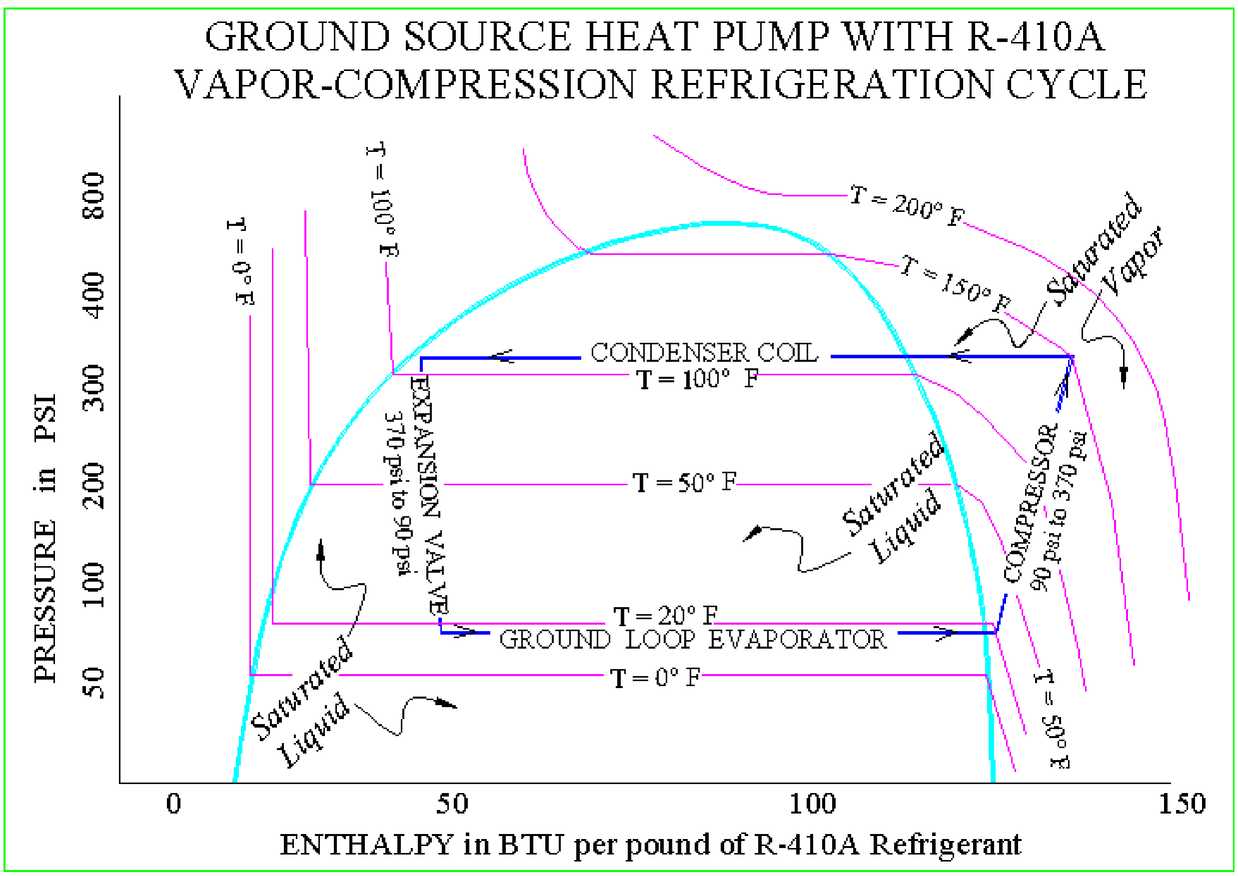


Figure 7 Pressure-Enthalpy graph for R-410A.

The “condenser” is not to be confused with the “compressor”. The condenser is in the air handler cabinet and is part of the process, but not part of the Split GSHP. In the language of the trade, it would be called an “evaporator” because the air conditioning mode is usually used for terminology. A blower fan circulates air from the building across the “condenser”. In heating mode, cool air from the conditioned space blows across the condenser, where the air is warmed for recirculation. It is forced through the duct system and registers into the rooms (where it loses heat to below 100°F) until the thermostat request of approximately 70°F is satisfied. Unlike fossil fuel systems that operate at 140°F, the ground source condenser is not as hot, thus resulting in improved efficiency and more air circulation. This additional ventilation adds to the improved comfort of geothermal heating. For this reason, baseboard radiators are not always suited to retrofitting with geothermal, unless more radiators can be added. Duct sizes are usually adequate, but should be checked if minimal. For larger buildings with 10-ton heat pumps, water-to-water GSHPs operating at 130°F maximum are feasible and often heat radiant floor systems. There is no change to the air filter operation or maintenance schedule to collect and remove room dust. A typical GSHP manufacturer might make three water-to-air GSHPs for every water-to-water GSHP. A water-to-water unit can also serve an air coil.

Because the air flows across the condenser and removes its latent heat, the R-410A cools and “condenses” into a warm liquid. It then passes by an expansion valve, where it expands and becomes a cold liquid. Expansion is essential to decreasing the refrigerant temperature to a value that is colder than the ground loop water solution that will reheat it.

In a building retrofit, the heat pump condenser can either use or replace the oil or gas sourced condenser in the existing air handler cabinet. It is important to check the age and to compare efficiency against the price of newer condensers when recommending replacement. Incidentally, R-410A, at higher pressure, will require a new coil. Unless the determination is to go with a water-to-water system, only R-22 or older lower pressure type refrigerants can be reused and utilized for both heating and air conditioning as shown in figure 8.

Figure 8 Condenser detail within the air handler cabinet. Copper tubes circulate R-22 here. (In the field, the technician will call this the evaporator coil, referring to its use in cooling mode.)

In this new installation, for extreme climate circumstances, a humidification/dehumidification system is located next to the condensor (referred to as the “evap coil” per tradition) to regulate moisture output (figure 9). Note that most blowers in the air handlers shown are GE ACM blowers, generally running at 1/3 horsepower and with 60% efficiency.Modern variable speed blowers are controlled through ECM (Electronically Commutated Motor) boards averaging 400 cfm. Air filters should have MERV (Minimum Efficiency Reporting Value) of 7.

Beside air source heat pumps that are not efficient in freezing weather, there are larger scale “Hybrid” GSHPs that use ground source water and an air source (cooling towers). They can be as efficient as pure GSHPs(http://hpac.com/plumbing-piping-pumping/ground-source-heat-pumps-0909/).

The difference between the air source and the water source from the ground is at the heat exchanger. It is this efficient transfer of heat from the ground loop fluid to the R-410A refrigerant that allows GSHPs to provide more heating or cooling for less electricity. For example, in winter when the outside air temperature is 30°F, the air sourced heat pump uses more electricity than the ground source heat pump making contact with 40°F loop water.

Figure 9 Humidification / dehumidification assembly located next to the condenser.

It is at the heat exchanger where the second law of thermodynamics occurs (heat flows spontaneously from a hot object to a cold object). Entropy is the tendency for the warmer ground loop water to get cooler as it comes near, but not in direct contact with, the cooler R-410A that then heats up. In air conditioning, the opposite occurs at the same heat exchanger.

This all important heat exchanger separates the *air sourced* from the *ground sourced* heat pump. Shown as the "Water / Refrigerant Heat Exchanger (Evaporator)" in figure 5 (called the "condenser" in the field), it is assembled in a coil configuration as shown in figures 10 and 11 in two separate GSHPs with similar insulated round coils.

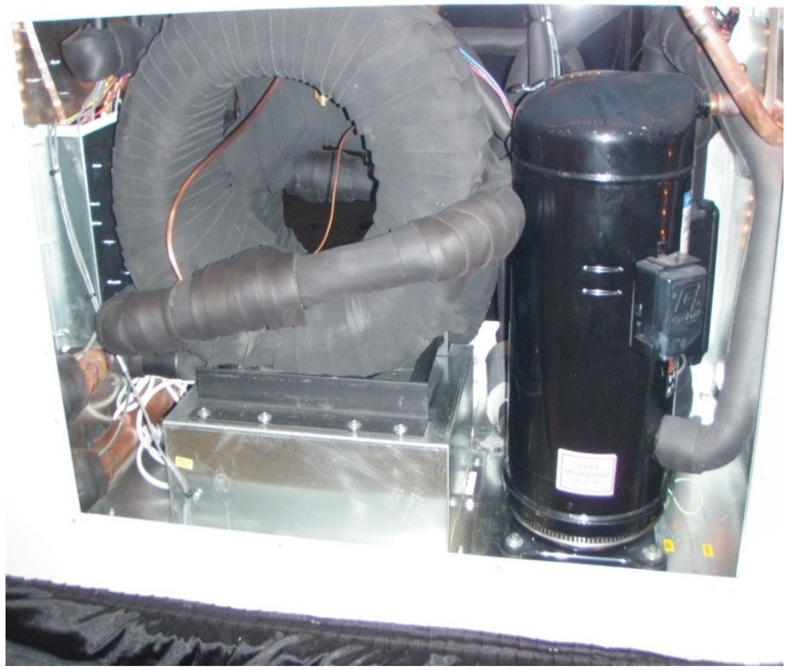


Figure 10 Heat exchanger.

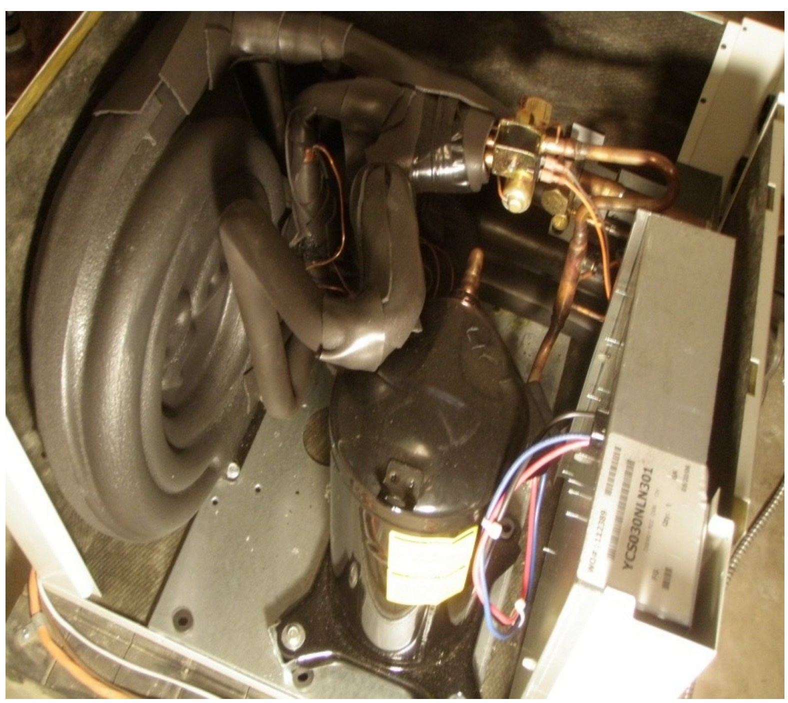
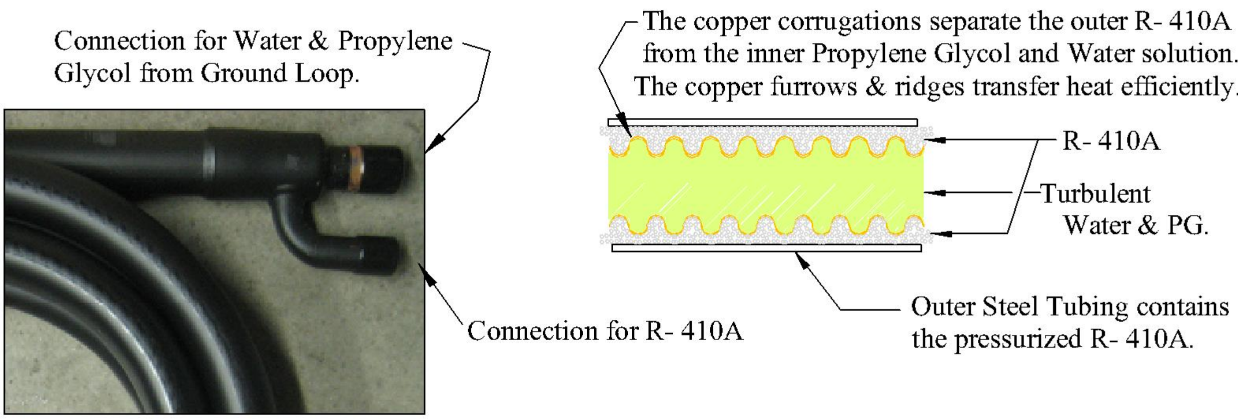


Figure 11 Another heat exchanger (sometimes a clamshell insulation).

Figure 12 Heat exchanging coil within the insulation wrap.

Figure 13 The way the loop water makes good contact with the R-410A refrigerant within this copper and steel coil is key to efficient GSHP operation.

One prominent manufacturer, Packless Industries www.Packless.com uses a patented process with the coaxial principle of a tube within a tube design. From the corrugated inner copper tube, good thermal contact (but no physical contact) is made in the coaxial heat exchanger. The fluids purposely flow parallel to each other to maximize evaporation in heating mode, and opposite each other to maximize condensing during air conditioning.



Coaxial Heat Exchanger Coil

Figure 14 Packless Industries

Note that Packless uses copper for closed loop and Cupro-nickel for open loop coax. Copper is about 5% more efficient but not as durable. There are 8 ridges per inch in a Packless brand tube compared to 6 ridges per inch in a Turbotec. Both products will hold about 1 gallon of R-410A.

To complete the cycle from figure 5, the warmer R-410A now as a cold vapor, goes back to the compressor where it is compressed to hot vapor again and sent to the condenser to resume the cycle.

Terminology reverses for the cooling process. The Heat Condenser becomes the AC Evaporator, and the expansion valve becomes the reducing valve, etc.

It is very important that AHRI approve the entire GSHP system to take advantage of certain state and utility rebates. Hooking up an approved GSHP to an air handler that is not approved by AHRI can be problematic for those seeking a rebate. Although the system will work well and meet efficiency verification standards, the lack of matching assembly certification can be a reason for rebate denial. Energy Star and tax credit requirements are also jeopardized. To see if the proposed unit is certified for a combined GSHP and air handler coil (referred to by AHRI as the Indoor Model), consult with the AHRI website : http://www.ahridirectory.org/ahridirectory/pages/wbahp/defaultSearch.aspx Simply find the GSGP manufacturer from the drop down box, type in the first three numbers of the GSHP model number, and see the available matching assemblies, or vice versa. For example, use Climatemaster and 026. During business hours, AHRI technical assistance operators can answer chart reading questions. Certificates are downloadable. Because R22 refrigerant is being phased out, air handler coils must, in almost all cases, be replaced by R410A coil indoor models. Be aware that some common coil manufacturers are not on the approved list. In one example, Bryant/Carrier and Rheem were the only approved matches for a proposed ClimateMaster split unit GSHP.

One way to verify installed performance during commissioning is to use the Verification of Installed Performance (VIP) form here:

http://www.cl-p.com/Home/SaveEnergy/Rebates/Geothermal_Heat_Pump_Rebate/

(closed loop Excel spread sheet third from bottom)

First developed in 2000, the VIP form is popular in some states since some utility company rebates require the GSHP to run at ≥ 85% of the rated Coefficient of Performance (COP, as described below) based on incoming water temperature. The designer should be familiar with the content of this form, which can be utilized once the system is operational. The category pull downs help with data entry to the form. Use your field readings for the amperage, pressure and temperature at the ports, and take temperature readings in the air handler plenum. Note, a typical 212 volt system might use 12 amps for the compressor, 1 amp for the flow pump and 1 amp for the air handler fan. The actual COP is computed within the form software at the end of the form, and the building owner can be assured of adequate efficiency. The form follows the Heat of Extraction (HE) or Heat of Rejection(HR) formula:

$$Q = K\ (T_1 - T_2)\ \times GPM$$

Where K = 485 for PG antifreeze or 500 for water alone. Field check must be close to HE or HR specked.

Example: 3ton system EWT
Where, T_1 = entering water temperature = 43°F
T_2 = exiting water temperature = 38°F

$$\Delta T = T_1 - T_2 = 43°F - 38°F = 5°F$$

And,
1 BTU raises one pound of water one degree F.
One gallon of water weighs 8 pounds
A 3-ton heat pump circulates

3 x 3 = 9 gpm = 72 pounds of water per minute.

For Delta T = 5F,
72 x 5 = 360 BTU/minute = 21,600 BTU/hr.
= almost two tons of capacity in a 3-ton nominal heat pump (OK).
So, 8.1 lbs. x60 minutes = 485 is used.

Coefficient of Performance COP

The Coefficient of Performance (COP) is the ratio of available heating/cooling capacity over the necessary energy consumption to obtain that capacity.

According to IGSHPA, the exact definition of COP:

$$\frac{Heating\ Capacity\ in\ BTU/hr}{Power\ Input\ in\ BTU/hr}$$

This efficient heat exchange in a GSHP causes the Coefficient of Performance (COP) to be more than three times better than conventional electric heat. For a closed loop, the standard COP of 3.3 (3.6 for open loop) means that 1000 kilowatts of electric power provide the equivalent heating of 3300 kilowatts. By contrast, a conventional plug-in electric heater has a COP of only 1.0. The higher the COP, the more cost efficient it is, depending on equipment, refrigerant and especially the incoming loop water temperature. GSHPs save electric cost and saving electricity is key.

A theoretically perfect machine with "Carnot COP" has no losses of heat dissipated by the compressor and pumps and fans, etc. that are accounted for in the real COP.

The COP is ≤ Temperature of the incoming warm loop water divided by the temperature drop as the loop water returns to the ground, in absolute units.
From Wikipedia:

$$COP_{heating} = \frac{(Q_1 - Q_2)}{(W_1 - W_2)} \le \frac{Temp_{hot}}{(Temp_{hot} - Temp_{cold})}$$

Where Q1 – Q2 differential is the amount of heat sent to a hot recipient body at Temperature hot, and W1 – W2 is the compressor work. Temperatures used are not Fahrenheit, but in Absolute Units

As ground temperatures cool in the winter, the "source" heat differs more from the "sink" heat inside the building where the temperature stays constant at the desired 68-70°F. This differential is called the "lift." As lift increases, more electricity is required to attain the same result. Thus, COP changes as a function of this temperature adjustment, but remains in the range of 3 to 4. Energy Star Standards are set by AHRI, the Air conditioning and Heating Refrigeration Institute (formerly ARI, the Air conditioning Research Institute).
http://www.ahrinet.org/ARI/util/showdoc.aspx?doc=1468

The ongoing testing program evaluates closed loop GSHPs under AHRI-330 at 32°F source heat and 77°F source cooling, including pumping costs to circulate the antifreeze solution through the loop field. AHRI-325(50), for open loop with source temperature of 50°F including pumping costs, is more efficient if the three requirements for water use can be met.

In summary, to reduce the large cost of winter heating, select a GSHP that is efficient at the low (30 to 40°F) loop water temperatures that will prevail during the coldest time of the year. The highest luxury heating model available is COP 5.0. Specifying a new GSHP in the 4.0 range is common.

During air conditioning mode, the Energy Efficiency Rating (EER) is the reverse for the cooling mode. A COP of 4.0 equals an EER of 13.6 because the BTU conversion to a watt hour is 3.412. The Seasonal EER (SEER) for real working conditions reach 15 and 16 easily and can be as high as 25-30 for expensive state-of-the-art systems with advances made in the industry.

As in most specification selections, GSHP products require minimal standards, such as Energy Star ratings, and the specifier must decide if the added expense for higher quality and efficiency is justified. A helpful guide from the Federal Energy Management Program is at this link:
http://www1.eere.energy.gov/femp/procurement/eep_groundsource_heatpumps.html#when

Selecting the Properly Sized GSHP

A rule of thumb is that one ton of heat pump capacity equals 12,000 BTU per hour, and for a typical 2000 sq. ft. home, a 3-ton GSHP produces 36,000 BTU per hour. Therefore, be sure to check specifications that could show Heating Capacity of only 27,000 BTU/hr. in second stage and 22,000 BTU/hr. in first stage. Also, design to heating and cooling capacities and not simplified tonnage ratings. By calculating the heat loss from R-values and air leaks, the capacity needed for various sized buildings is computed. ACCA Manual J or the ASHRAE Handbook of Fundamentals may be used to determine Heat Loss/ Heat Gain more precisely, along with the corresponding residential equipment GSHP sizing loads. The methodology is the same for all types of heating and cooling systems (ACCA Manual D is for ducts. ACCA N for commercial). Degree Days and Bin Hours can be used in software programs to determine the Load profile more specifically.

For a quick analysis of the heat loss, designers can easily measure the building envelope, to compute walls, ceilings and fenestration areas, and arrive at a reasonable BTU/ hour design. Per http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/heatloss.html

Heat Loss Rate = (Area x Temperature differential) / Thermal Resistance of the assembly.

$$\frac{Q}{R} = \frac{Area \times (Temp_{Int.} - Temp_{Ext.}}{Thermal\ Resistance\ of\ Building\ Components}$$

This example determines loss through walls with insulation rated at R-10:

Example: Consider a 40' x 30' building with an 8' high ceiling.

Area = (80 + 60) x 8 =1120 sq. ft.

For an inside temperature of 70°F and outside at 0°F degrees,
The rate of heat loss through the walls alone is:

$$\frac{Q}{R} = \frac{1120\ \text{sq. ft.}\ x\ (70°\text{F} - 0°\text{F})}{10} = 7840\ \text{BTU / hour}$$

Adjust for fenestration, add ceilings and floors, infiltration air leaks, and leaks of ductwork in unconditioned space. Find the total BTU/ hr. required to heat the building and suppose that it totals 23,000 BTU/hr. Because they are manufactured to the nearest half ton, select a GSHP with a Heating Capacity of 24,000 BTU/hr. that might have a Cooling Capacity of 30,000 BTU/hr. and rated at 2 ½ tons. Incidentally, tonnage is an AC term (12,000 BTU/hr.) that historically referred to the energy necessary to melt a ton of ice, but is now used for GSHP heat. If sizing smaller, the building will require more auxiliary heat, however 115-volt service is

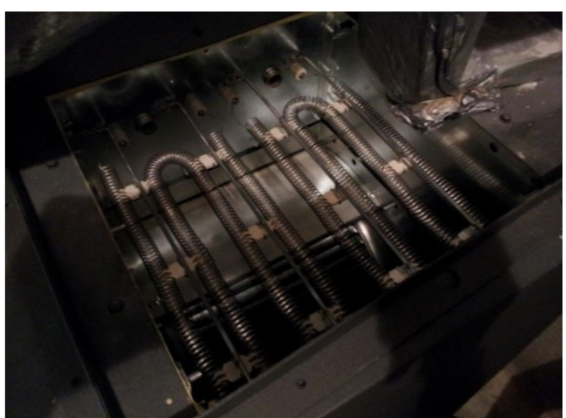


Figure 15 Inefficient (COP=1) Duct Heater, 10kW rated.

inadequate for strip heaters.

An old rule of thumb used to be that tonnage selection should be for the peak sensible cooling load, with an increase of 25% to account for the heating load. But with advances in

GSHP technology throughout the years, for northern heating climates, the procedure is to now select a GSHP that can handle 100% of the heating load, or slightly less. Choose a unit that is within 25% for cooling mode. Some rebate offers require 95% annual capability before backup must kick in. The two-stage compressor can use the 67% first stage to address latent (humid) heat during cooling. All the capacities in first and second stage heating and cooling are tabulated in the Performance charts. The blower fan control can be adjusted, as well, so that summer time air is cool, yet not humid and "clammy". Far northern regions with frequent subzero temperatures might not be suitable for GSHPs. Air-to-air heat pump efficiencies in those locations are poorer than in the south where heating is accomplished with warmer outside air.

In the south, a smaller, all-in-one GSHP will meet the design parameter for higher peak heating outside temperatures in the 30-degree range that occur for limited duration and days within a year. Zone maps are available, but it is best to calculate temperature differentials based on the region.

Using the above equation (not example), to provide air conditioning to the inside with an outside temperature of 105°F, Delta T = 35 degrees or exactly half of the heat loss rate of the original 7840 BTU / hr. which then comes to 3920 BTU/ hr. Therefore, typical GSHPs are oversized in the cooling mode. Taking this in to consideration, remember to add cooling loading from appliance and light heat, etc. including the GSHP. ACCA software is useful for this.

Climates that predominantly use air conditioning should address sensible and latent cooling loads. The sensible load is the dry bulb temperature of the thermostat, while the latent load accounts for relative humidity. An overly large GSHP might not run frequently enough when air conditioning is needed and might not remove enough humidity. The air handling blower can possibly address this by delivering 365 cfm/ton for cooling and 410 cfm/ton for heating.

For a retrofit, confirm and replace the same tonnage unit that is removed, but be aware that many existing air conditioners, air source heat pumps, and oil/gas fired furnaces are oversized.

As with more specific ground loop field design, designers can pay a nominal fee to use software available from Geo Connections, Inc. of South Dakota (www.geoconnectionsinc.com), which was affiliated with IGSHPA. By completing the 73 item worksheet (and 12 items for ducts) a specific GSHP tonnage can be determined. In addition, GSHP manufacturers have trained dealer representatives who can size units based on building wall, ceiling areas and R factors. Another helpful design link is www.Geokiss.com, and a simple online Residential Load Calculator is here: http://www.shophmac.com/info-center/hvac-calculators/heat-load-calculator.php

Finally, another source is IGSHPA or a manufacturer's Windows-ready GeoAnalyst (ClimateMaster, Bosch and Enertech offer it) application that is downloadable for $50 per year, or free.

By selecting a small GSHP, cost savings can be attained, and a backup system can be used for the days when outside temperatures drop below design. Be sure the loop field is not overtaxed with the frequent cycling on peak demand days, lest Entering Water Temperature (EWT) drops and so COP efficiency drops. COP depends on other factors, but EWT is critical. Backup can be a separate electric floor heater, an older existing fossil fuel system or an auxiliary electric strip backup within the air handler. A small heat pump will also run more frequently (about 1 third of the time on cold days or 4 to 5 cycles per hour) and operating costs will increase. Some controls shut off GSHPs if the thermostat is not satisfied in 15 minutes and switch temporarily to a more electrically expensive backup. Night setback must address this issue.

At a Connecticut Society of Professional Engineers meeting, a PE who had installed a GSHP and horizontal loop field at his new home reported that he also installed a gas back up heating system, but had never needed or used it. Few in the northeast with proper systems used backup.

It is best to keep within the conventional uses of about three tons for a 2000 sq. ft. normally insulated and sealed home in the mid-north. In sizing GSHPs, remember that good judgment is needed, but the penalty is slight loss of efficiency, not a malfunctioning system. Over-sizing or under-sizing by a half ton will not greatly change the already reduced monthly electric bill. Still, it is best to not oversize, lest the air conditioning becomes overwhelming even in first stage. It is important to strike a balance.

Installing the GSHP by the Manual

A homeowner's manual for Installation, Operation and Maintenance will come with the shipment of the 200 to 250 pound split GSHP. On-line manuals can be consulted at any time by the geo-designer interested in the GSHP specifics before it arrives (50-page sample manual http://www.docs.hvacpartners.com/idc/groups/public/documents/techlit/97b0048n01.pdf).

Various tables will show operating specifics according to the model number. The Manual should also include a Warranty Certificate that is good for five to ten years. The major GSHP manufacturers are rated by how quickly they respond to Warranty issues and home owners need to know that maintenance for a problem will not be costly or monopolized by only a few contractors in the region.

For installation choices, the manual will compare indoor and outdoor versions of its GSHP product line. Packaged units can be horizontal or vertical with upflow or downflow and have self contained refrigerant. Noise can be a factor in a basement, but there is more efficiency in the semi-conditioned space. All units must be kept level and sealed against rodents and insects. Indoor units cannot freeze or be in humid areas, so the designer must select a location in the basement or utility room that is accessible. If that is uncertain, some GSHPs on display at the IGSPHA convention, such as Bard Manufacturing Company, showed panels that can be removed from either side for future maintenance. To facilitate ease of installation, there is a left or right duct exit from the air handler portion; water connections can insert from both sides. Also, the filter rack flips to either side and the strip heater can be accessed from two sides.

Layout and access where the loopfield HDPE enters through the concrete and connects to the air handler and possibly hot water tank must be considered. GSHPs must be placed on soft, dampening air pads, neoprene type pads or rubber mounts to muffle sound and vibration. Installing in drop ceilings is discouraged because of maintenance access issues.

Condensor (Evaporator) coils must be compatible with R-22 or R-410A refrigerants; warnings on proper handling are given. Air handler characteristics must match the GSHP tonnage as shown in the charts. For example, a 3-ton GSHP might require a 48°F Evaporator Temperature, 1200 cubic feet per minute of air handing, and a heat capacity of 37-42 MBTU/hour.

Figure 16 Two-stage split GSHPs being installed in a crawl space.

On the left: a 2-ton unit (26,400 Btu/hr. cooling or 19,500 Btu/hr. heating, part load 1st stage cooling is 20,800 Btu/hr.)

On the right: a 3-ton unit (37,300 Btu/hr. cooling or 27,000 Btu/hr. heating, part load 1st stage cooling is 27,100 Btu/hr.)

The manual also reminds the HVAC installer about the outside HDPE solid or heat fused loop. Inside connections can be conventional and fusing is not required, but Schedule 40 PVC is discouraged, especially during the 50-100 psi pressure test conducted usually before backfilling. Instead, it is recommended to use HDPE or Sched 80 and to insulate the interior, 1" diameter, rubber hose pipe to avoid sweating.

The interior piping can be made to withstand the low operating pressures of 5 to 10 psi or up to 30 to 50 psi, if the required flow of 9-10 gpm for a three ton GSHP is achieved. At minimum, a positive 3 psi is needed in the loop to activate the flow controller pump. Lower pressures from a canister type system will generally prolong equipment life. Additionally, gages on the system allow for monitoring. For a successful installation, the environment of varying pressures and freezing temperatures must be addressed throughout. A freezing loop pipe outside can damage a nearby water supply line. Loop pipe not ready for use that collects water without antifreeze can be damaged, even though HDPE can withstand a blow from a sledge hammer.

The installation guide will describe how to set the low water temperature jumper and the purge and charge sequence of the antifreeze solution loop. A flush cart with 1.5 HP is needed for a pressurized closed loop. Charging, commissioning and leak testing need not be done by EPA certified technicians, unlike R-410A installation. Contractors may improvise with a large pail and pump or use a specially constructed unit, such as the flush cart (figure 17), that may be purchased or rented:

Figure 17 Flush Cart

All air and debris is removed out of the loop, and the addition of the 15-25% propylene glycol solution or ethyl alcohol or methenol, etc. is made easy with a flush cart. No dirt or debris can enter the loop, so the filter in the flush cart is removed as shown (figure 18). GSHPs should never operate during construction when dirt and debris could foul the condenser coils.

Figure 18 Removing filter from the flush cart.

Flushing requires more pumping power than circulating, so sometimes a fire truck pump is strong enough to do the job. Unfortunately, retrofitting a house with 115 volt service might only power a 1 to 1 1/2 hp pump. A way to verify if a loop has air is to check pressure, remove an ounce of water and PG and see if pressure dropped, which it will if undesirable air is in the loop pipe.

Other factors concerning the GSHP installation involve supplying adequate electric power. The manual should be checked to be sure a typical 30 or 40 amp whip supplied by an electrician will be sufficient. Wire run length is inconsequential. A drain pad is needed where condensation could occur at the air handler, but is not needed for a split GSHP.

During commissioning, R-410A HVAC technicians will check the required superheat and subcooling to be sure the unit is not overcharged or undercharged. Line sets should not be >50' or more than 20'-30' in rise. Therefore, attic handlers might be better supplied by water than R-410A.

Other than changing air filters at the air handler, making sure that the condensation pan has a proper outlet for draining and keeping the GSHP cabinet sealed and dust-free, there should be no increase in maintenance outside of what is normally expected for a refrigerator or air heat pump appliance. In addition, the propylene glycol closed system should last many years.

Flow Center Pump Controller and Low Voltage Controls

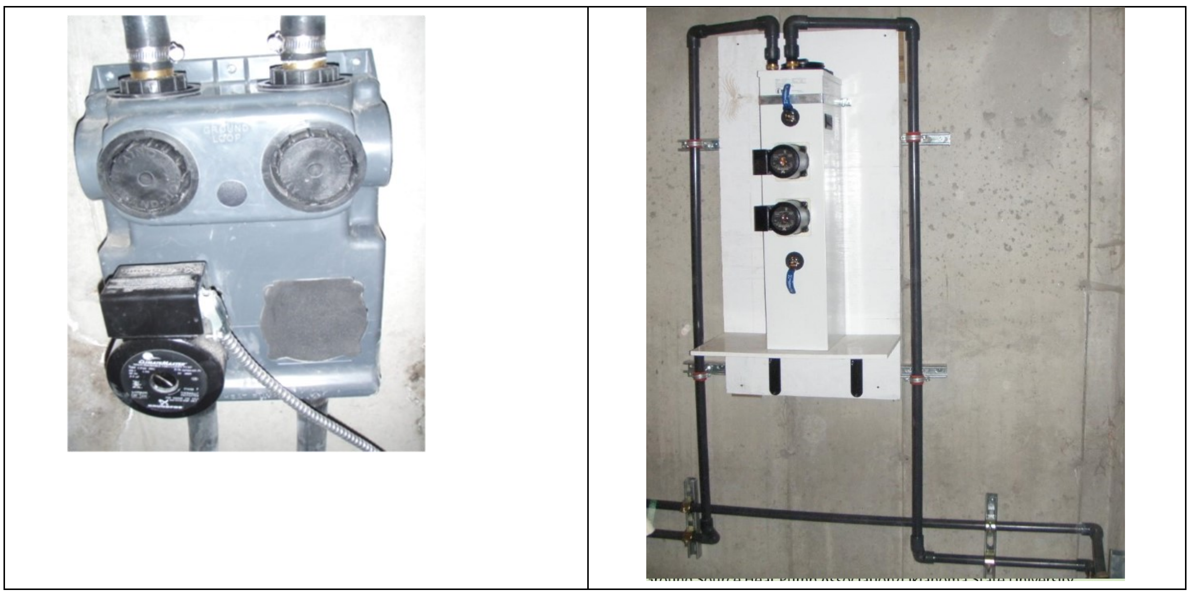


Figure 19 Grundfos Flow Controller Model AFCG2C1 with earth loop pipes above and heat pipe rubber pipes below. Approximate purchase cost is $700. Non pressurized flow center option, to the right. It is actually about 5 psi and available with smart controls. They can be more costly, but could eliminate the need for flushing.

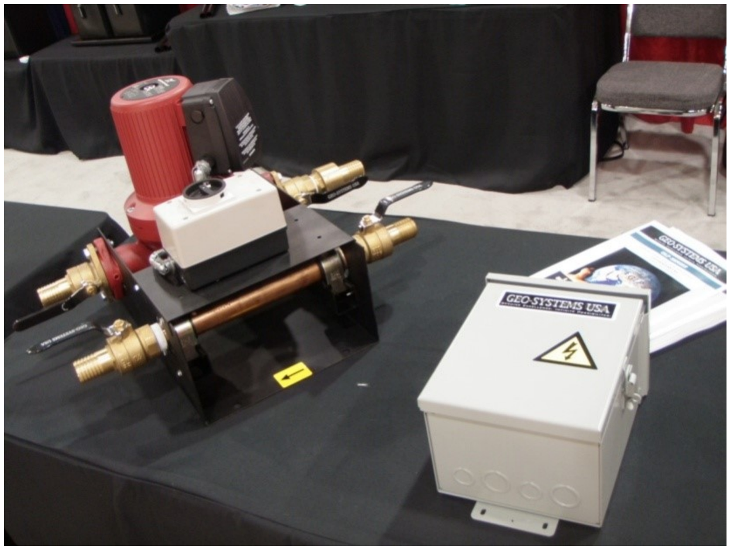


Figure 20 A Grundfos Flow Controller on display at the IGSPHA Exhibition.

The Flow Controller is the pump that circulates the water & antifreeze solution in the earth loop. For small commercial and residential, circulating pumps are usually single stage, and not variable speed. Newer heat pumps are available with the circulator pump already installed in the heat pump cabinet. This allows for Plug and Play installation.

Figure 21 GSHP and Flow Controller installed.

The Installation, Operation & Maintenance Instructions for the flow controller shown in figure 19 can be found at the following link:

http://www.climatemaster.com/downloads/97B0015N01.pdf

Within the 32 page booklet there are two charts on pages 16 and 23, figure 22, that can aid in sizing the flow controlling pump.

The 3-ton heat pump presented earlier with a 9GPM flow and serving a typical small building can be used as an example for determining the appropropriate size flow controlling pump. .

First, consider the 25% propylene glycol antifreeze solution chart.

- Consult the PG solution recommendations for desired antifreeze temperature on its container.
- Consult the SUNCAM geothermal trench design course, for 1000LF of 1 ¼" ground loop pipe.
- From the table in figure X, read 2.07' of head per 100' = 20.7' of head total resistance due to HDPE skin friction.
- Add in the pressure drop across the heat pump and the interior rubber piping according to the additional chart (use about 7') and note that even the small single pump capacity just meets 27.7' at 9 gpm.

Recall that there is no additional head despite burial depth, because the closed loop is pressurized to at least 3 psi or less with a free standing column. This allows the addition of water and propylene glycol as the loop expands and contracts with temperature changes and requires no flush cart. The operating pressure does not affect interior skin friction pumping pressure and is independent of R-410A pressure.

An optional Hydronic Diaphragm Expansion Tank with Bladder (under $70) will keep pressure more stable and can be outfitted with a pressure gage for monitoring purposes and to ensure that the system is operating as designed

An open loop water source from a deep well does involve using electricity for pumping, depending on the ground water level, which subtracts from the COP but uses water that is almost always at 50°F if properly bled off and not just returned to a standing column. Because the source water for the open loop supply is warmer than the closed loop, approximately 2 gpm and not 3 gpm per ton is required. Flow controller pumping will differ from closed to open loop.

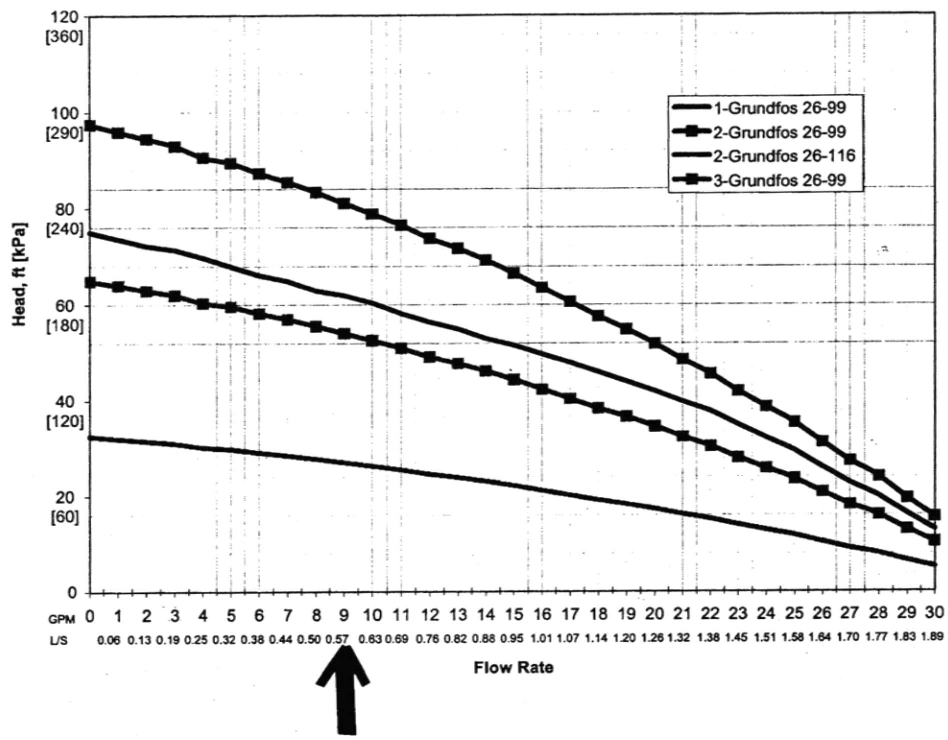
Of course the larger 2” ground loop pipe has even less resistance, and if ¾” slinky loops are used, and 4 of them enter a fused manifold, flow is 9/4= 2.25 gpm = 1.77’ of head per 100’.

Check the IGSHPA Manual to be sure that flow in the 2” HDPE loop pipe is turbulent for good heat exchange. Although the smaller HDPE loop field sizes are easier to install, the head loss is greater, as shown, and electricity used to power the Flow Controller contributes about 10% to the overall COP and EER. A 3-ton GSHP that requires a second Flow Controller at 1/6 horsepower will require 200 watts of additional power, effectively reducing the COP with little added benefit.

The charts refer to SDR11 and Sch. 40 pipe that is not used for ground loop piping (HDPE is), but the internal skin friction is similar. The chart in this booklet shows 1, 2 or 3 Model 26-99 pumps in combination. Without exceeding the flow controller capacity, select the model that best fits.

FLOW CONTROLLER PUMP CURVES

Chart 2: Flow Controller Performance



GEOTHERMAL CLOSED LOOP DESIGN

Table 6b: Polyethylene Pressure Drop per 100ft of Pipe

Antifreeze (30°F [-1°C] EWT): 25% Propylene Glycol by volume solution - freeze protected to 15°F [-9.4°F]

Flow Rate	3/4" IPS SDR11			1" IPS SDR11			1-1/4" IPS SCH40			1-1/2" IPS SCH40			2" IPS SCH40		
	PD (ft)	Vel (ft/s)	Re	(ft)	Vel (ft/s)	Re	PD (ft)	Vel (ft/s)	Re	PD	Vel (ft/s)	Re	PD	Vel (ft/s)	Re
1	0.42	0.55	636	0.14	0.35	507	0.04	0.21	389	0.02	0.16	346	0.01	0.10	278
2	1.41	1.10	1271	0.48	0.70	1013	0.15	0.43	798	0.07	0.32	692	0.02	0.19	528
3	2.86	1.66	1919	0.98	1.06	1534	0.30	0.64	1187	0.15	0.47	1017	0.04	0.29	806
4	4.74	2.21	2554	1.63	1.41	2041	0.50	0.86	1595	0.24	0.63	1363	0.07	0.38	1056
5	7.01	2.76	3190	2.41	1.76	2548	0.74	1.07	1985	0.36	0.79	1709	0.11	0.48	1333
6	9.64	3.31	3826	3.31	2.11	3054	1.02	1.29	2393	0.49	0.95	2056	0.15	0.57	1583
7	12.62	3.87	4473	4.33	2.47	3575	1.34	1.50	2782	0.64	1.10	2380	0.20	0.67	1861
8	15.94	4.42	5109	5.47	2.82	4082	1.69	1.72	3190	0.81	1.26	2726	0.25	0.76	2111
9	19.59	4.97	5745	6.73	3.17	4589	2.07	1.93	3580	1.00	1.42	3073	0.30	0.86	2389
10	23.56	5.52	6380	8.09	3.52	5095	2.49	2.15	3988	1.20	1.58	3419	0.37	0.96	2667
11	27.83	6.08	7028	9.56	3.87	5602	2.94	2.36	4377	1.42	1.73	3743	0.43	1.05	2917
12	32.41	6.63	7663	11.13	4.23	6123	3.43	2.57	4767	1.65	1.89	4090	0.50	1.15	3195
13	[redacted]			12.80	4.58	6630	3.94	2.79	5175	1.90	2.05	4436	0.58	1.24	3445
14				14.58	4.93	7136	4.49	3.00	5564	2.16	2.21	4782	[illegible]	[illegible]	[illegible]

Figure 22 Excerpt from Installation/Instruction manual for Model AFCG2C1 flow controller.

Programmable Control Panel on a GSHP

An overview for the building professional is given, but complicated low voltage control systems should be wired by experienced technicians. A Control Panel circuit board inside the split cabinet of a GSHP, located next to the compressor is shown in figure 23.

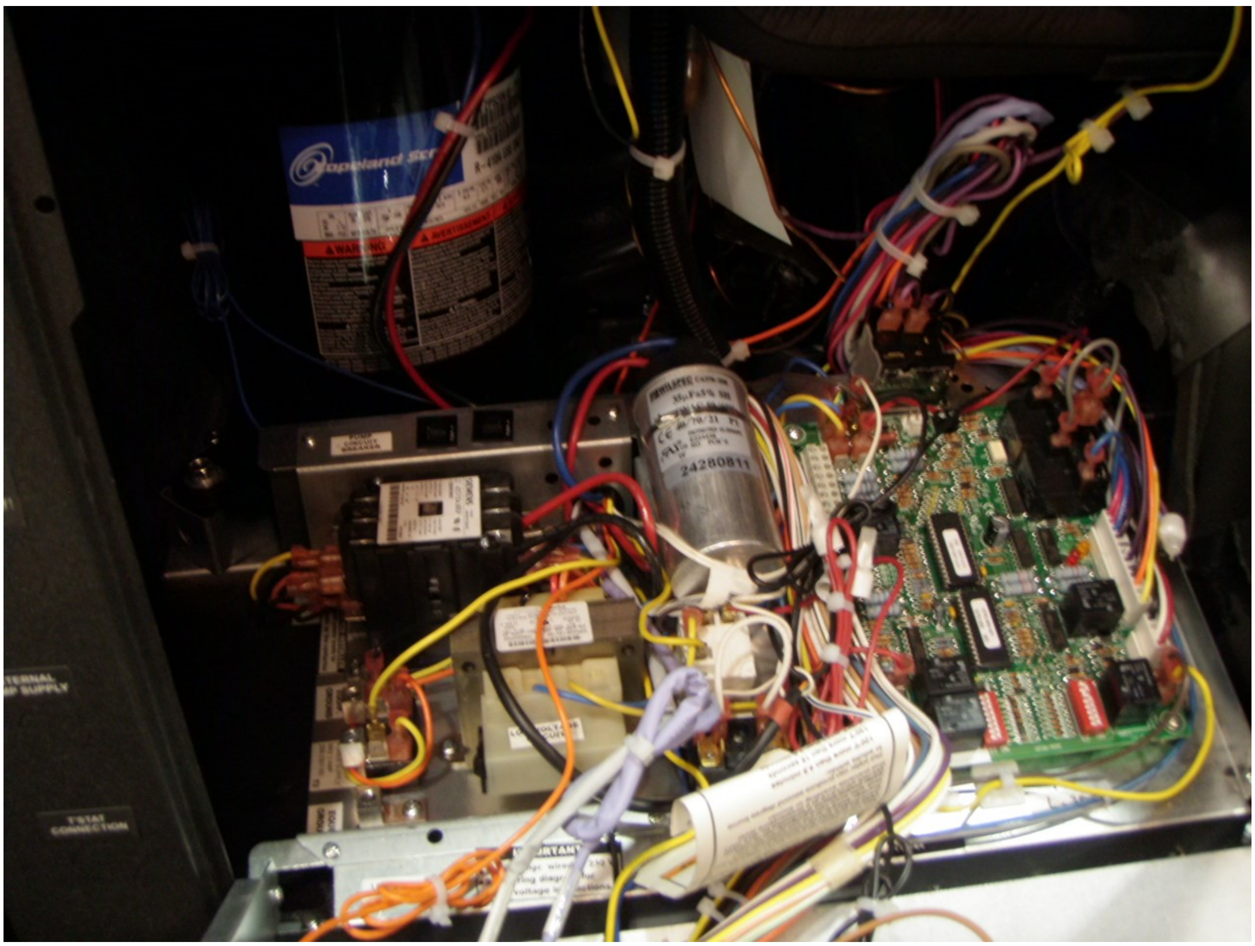


Figure 23 Control panel circuit board inside the split cabinet of a GSHP next to the compressor.

In addition to this circuitry, an accessible Control Panel is usually added to the air handler with wiring going from the thermostat(s) to the GSHP circuitry above and to the blower fan. For heat control, the GSHP activates and warms the coil before cold air blows across it when heat is demanded, and the blower fan stays on after the GSHP has turned off to provide the remaining heated air to the conditioned space.

One example of a commercially available control system is the BMPlus Zone Control System. Information for the technician on this unit is available in the 16-page Technical Bulletin that comes with purchase or on line at http://www.ewccontrols.com/acrobat/090375a0228.pdf

The installed BMPlus Zone Control System is shown in figure 24. The Technical Bulletin includes a diagram of the board with a legend describing the purpose of each Light Emitting Diode (LED), the associated I/O at each wiring terminal, and the location for input power. A blinking light means power is coming to the board.

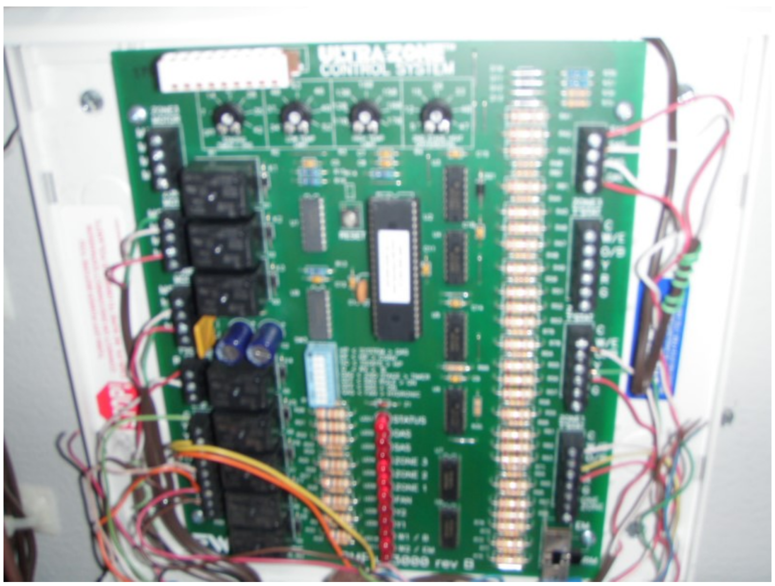


Figure 24 BMPlus Zone Control System.

When the panel is wired, the Dip Switch Settings should be ink recorded on the form within the Bulletin to document the type of GSHP, thermostat controls, Reversing Valve signal, and timers for the two stage compressing and multiple zone controls, etc. Among the seven built-in delay timers included in the BMPlus Control System are:

- Start-up delay timer- Fixed at 3 minutes.
- Short Cycle timer - Fixed at 3 minutes.
- Change over timer - Fixed at 4 minutes.
- Opposing Call timer - Fixed at 5 to 20 minutes. Homeowner should be told that switching from heat to air conditioning should take 5 to 20 minutes, but only to occur a few times a year.)

- (Second Stage timer – Off, but adjustable from 7 to 42 minutes.
- Supply air timer - Fixed at 3 minutes.
- Purge delay timer - Fixed at 1.5 minutes.

Look for separate Lock out boards and ECM boards (Electronically Commutated Motor) to control the air handler. Advanced controls can ignore a defective thermostat or wiring problem that requests simultaneous heating and cooling, while continuing to serve legitimate zones. For that reason, check the Source Freeze Setpoint at 30°F or 15°F if lockouts occur frequently.

Sophisticated control panels can detect incoming loop water temperature and adjust automatically. The programmable Smart Control Panel located directly on the GSHP is a new feature that keeps efficiency high by monitoring incoming loop water temperature to decide if the backup strip heater is necessary or not. Another feature is its interaction with photovoltaic cells on the roof, thereby powering the GHSP when the sun shines.

Beyond the controls, is system performance monitoring, such as at
www.groundenergysupport.com and https://symphony.mywaterfurnace.com

These have on line dashboards that allow the owner, engineer and contractor to see when the unit is running and for how long, plus BTU's generated and Entering and Leaving Loop Water Temperature, Operating Cost, etc.

Hot Water, A Water to Water GSHP and A College Lab

Figure 25 A desuperheater Hot Water Generator (HWG) for making domestic hot water.

At some point in the project, a decision must be made whether or not to add the HWG at the beginning , since it can be added later at little extra cost. Sometimes the desuperheater comes as a standard feature with the GSHP and can be removed to save perhaps $300-$400. If moving forward with the installation, connect in-line to an insulated 50 gallon or larger storage tank. Heat recovery is efficient during summer times and in warm climates. But, be sure to verify the efficiency of running a large GSHP just to heat water during the Spring and Fallsince this is when it would not normally run. Also, size the pump and loop 10% greater for the additional peak wintertime load during heating season. It might be prudent in a retrofit to use hot water heating during the summer only. This process can use between 3000 to 6000 BTU/hr. with a safety lock out at 130°F degrees.

For the tax credit & state rebates seen at www.DsireUSA.org, the EPA rates water-to-water GSHPs as Energy Star for the tax credit: http://contractormag.com/news/ahri-geothermal-pumps/.

A sample pump module kit installation manual is here: http://www.bardhvac.com/digcat/volume_3_cd/install_pdf_file/2100-517(B).pdf. It describes control board sequence of operation, how the heat recovery unit operates, thermistor sensors, and how to clean the coil with phosphoric acid if scaling occurs.

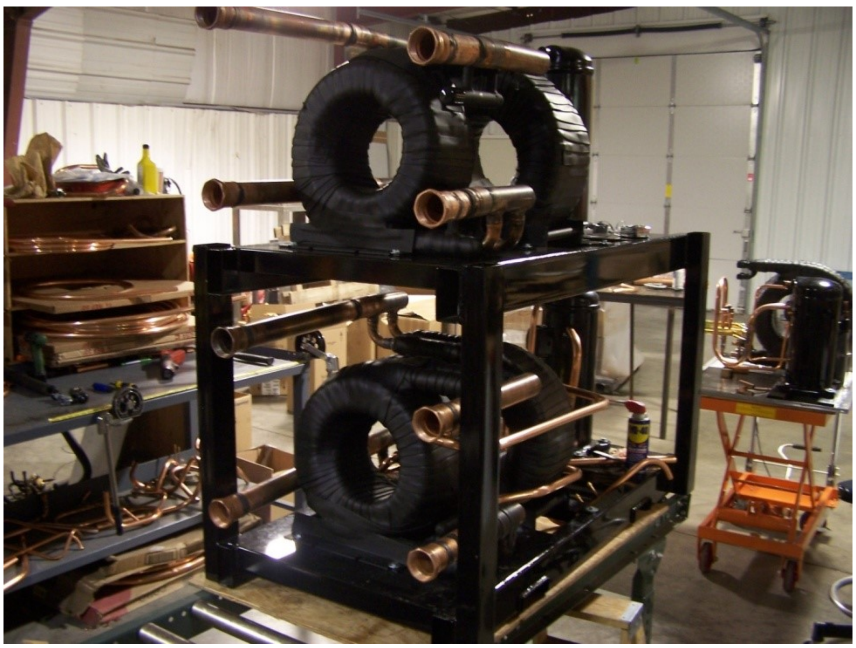


Figure 26 15-ton water-to-water heat pump. *Special thanks to Aaron Sorenson EIT, (now with Bosch) for these photos in fig. 26 and 27, and three earlier ones.*

Geo Furnace Manufacturing of South Dakota built this 15-ton water-to-water heat pump as shown in figure 26. There can be one or two separate heat exchangers, as shown, compressor(s) in the back. These larger units can achieve 125°F output water and peak up to 145°F degrees.

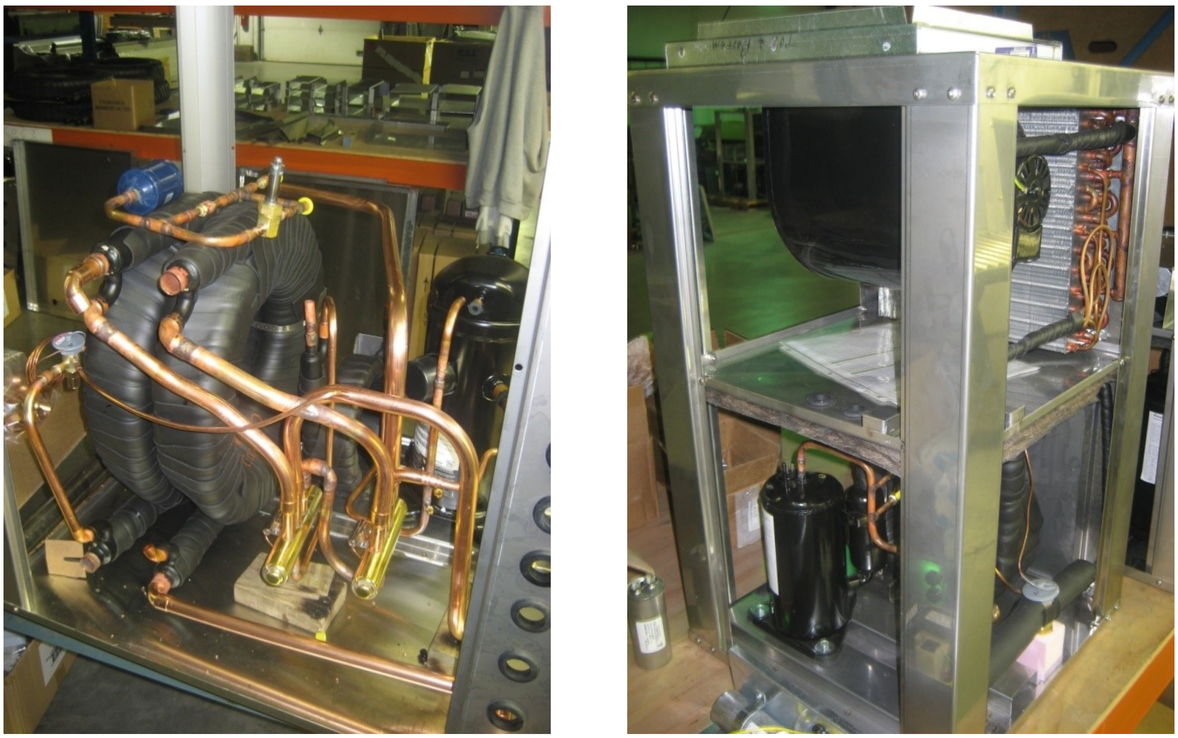


Figure 27 Heat Pump under construction

Another water-to-water company, Ice Kube Systems, makes a GSHP that has no reversing valve and cruises at 120°F with peak of 145°F. Their smallest unit, at 7.5 tons, handles about 7500 sq. ft. and sometimes has application for heating swimming pools.

Steam heat can't be converted, but radiators can if adequately sized, and radiant heating systems can be retrofit. Recent advances do allow smaller tonnage units to be used for radiant heating, so expect more water-to-water GSHP applications in the future. Chilled beams are another application, but residential air conditioning through duct work remains conventional. Water to Water GSHPs not on AHRI.net can be reviewed at www.EnergyStar.gov

ClimateMaster uses this image from its Factory Floor (fig. 28) in a marketing package. The 16 Copeland Compressors on the pallet are ready for installation in the GSHP cabinets. A diagram below (fig. 29) shows how scroll compressors operate. Simply energize the solenoid to go to Stage 2.

Figure 28 ClimateMaster factory floor.

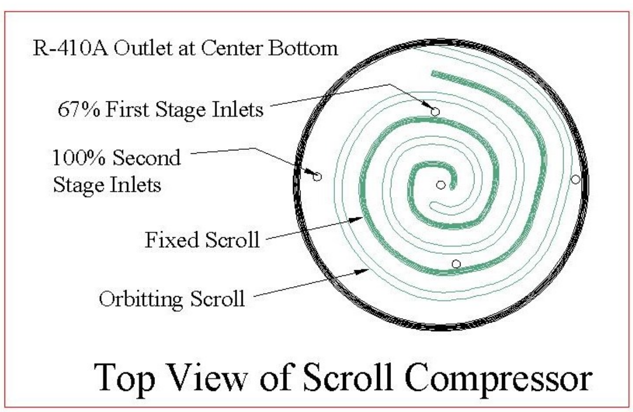


Figure 29 How scroll compressors operate. http://www.youtube.com/watch?v=IOL45plqJv4

Console GSHPs that are placed within the living space, like a piece of furniture or appliance. These are less than one ton to heat or cool one large room only. The issue of noise is a factor because the compressor is not silent, and each console requires its own dedicated Flow Controller. Look for advances by the GSHP manufactures to make these more and more suitable for installation.

Figure 30 Console GSHP that can be installed within the living space.

New Advances by Daikin and Mitsubishi use a water source for their Variable Refrigerant Volume (VRV) technology. One GSHP with multiple R-410A lines to various air handlers, can serve several zones at once. These are gaining new ground in source heating and cooling applications. Look for more advances in Soft Start technology to save on electricity at start up. An energy saver device that uses efficient soft start technology is the GeoStart that costs about $300-$400, but can reduce electric start up by 2/3.

Figure 31 How today's college students are being taught.

The large blue water tank (fig. 31) at this Eastern Maine Community College HVAC lab acts like a ground loop field so that technician students can work on and learn about the white Split GSHP to the right.

Sample college web sites discussing GSHP:

- Oregon Institute of Technology: http://geoheat.oit.edu/bulletin/bull25-3/art1.pdf
- Virginia Tech: http://www.geo4va.vt.edu/A3/A3.htm

Manufacturers conduct educational seminars about their specific GSHPs and bring a wealth of knowledge to the HVAC contractors and designers who attend. Figure 32 shows an Enertech Manufacturing demonstration of a one ton portable GSHP that is used to train technicians to work with and test superheating and sub-cooling of R410A.

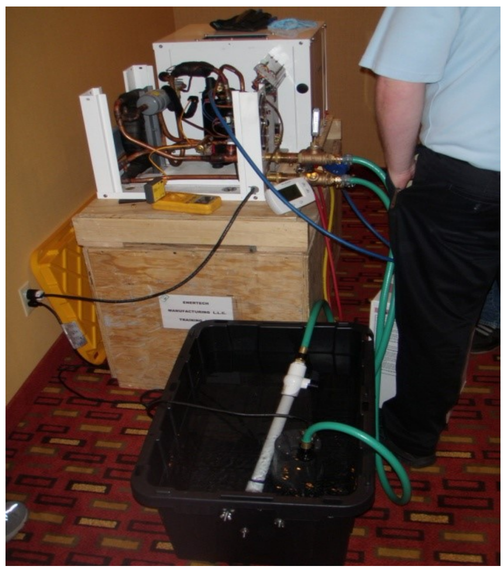


Figure 32 Enertech Manufacturing demonstration.

Figure 33 shows a closer view of the system set-up of the demo unit from figure 32. Note the following components:

- Insulated coax to the left.
- Grey dryer near the coax.
- The thermal expansion valve (TVX) swirl at the top.
- The central brass reversing valve.
- The black compressor.
- The electronic control boards on the right.
- The temporary blue line connects to the R-410A supply for testing.

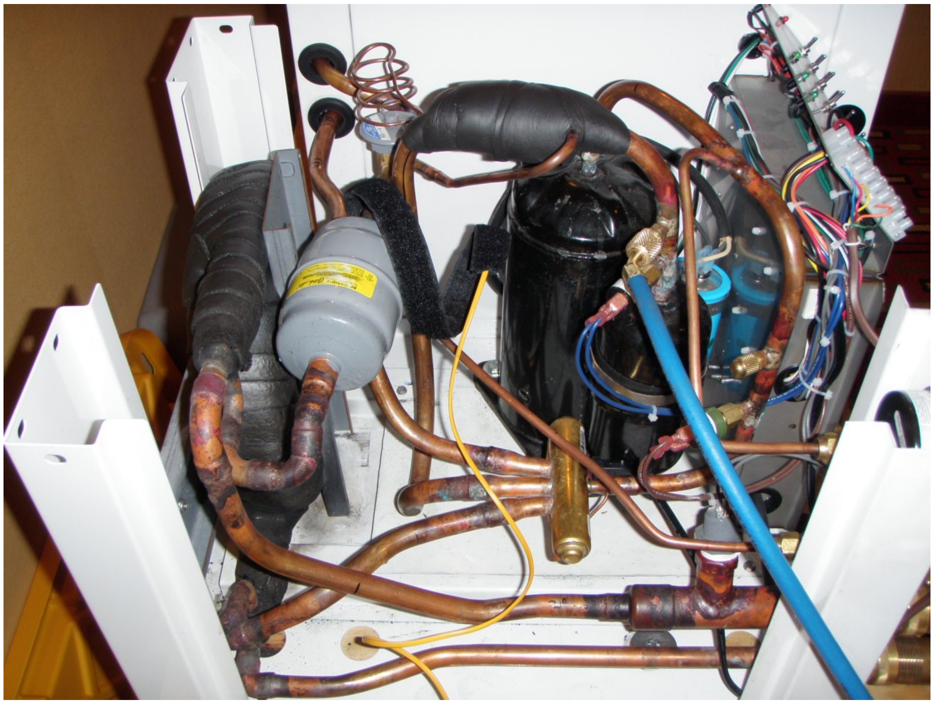


Figure 33 Close up of Enertech demo unit.

Conclusion

Ground Source Heat Pumps are an efficient way to harvest a natural resource from the earth. The limited thermal property of the soil is not expected to provide vast benefit to the land owner, but does allow the ever more efficient technology of heat pumps to easily warm or cool a small residential or commercial building. Most would agree that reducing energy usage by substantial factors is a worthy goal to pursue.

Figure 34 Split System installed close to wall loop penetration with flow center & 10 gals of antifreeze.

The time has ended when HVAC designers specify only the systems with which they are most familiar. Under the leadership of the engineering and building construction professions, GSHP system utilization is poised to expand dramatically. Whether for new construction or retrofit, GSHPs make good economic sense. It is not the low hanging fruit but the fruit on the ground! GSHPs meet three important national energy policy goals: lower dependence on foreign fossil fuels, local energy jobs and cleaner air.

Leverage the base knowledge from this course by returning to the many web site links. This will familiarize you with the details of GSHPs. Consider taking classroom style IGSHPA installer certification training, which will be easy after passing this course. Use your analytical, mechanical, electrical and construction experience skills to help small building, energy users take advantage of the many benefits offered by Ground Source Energy.