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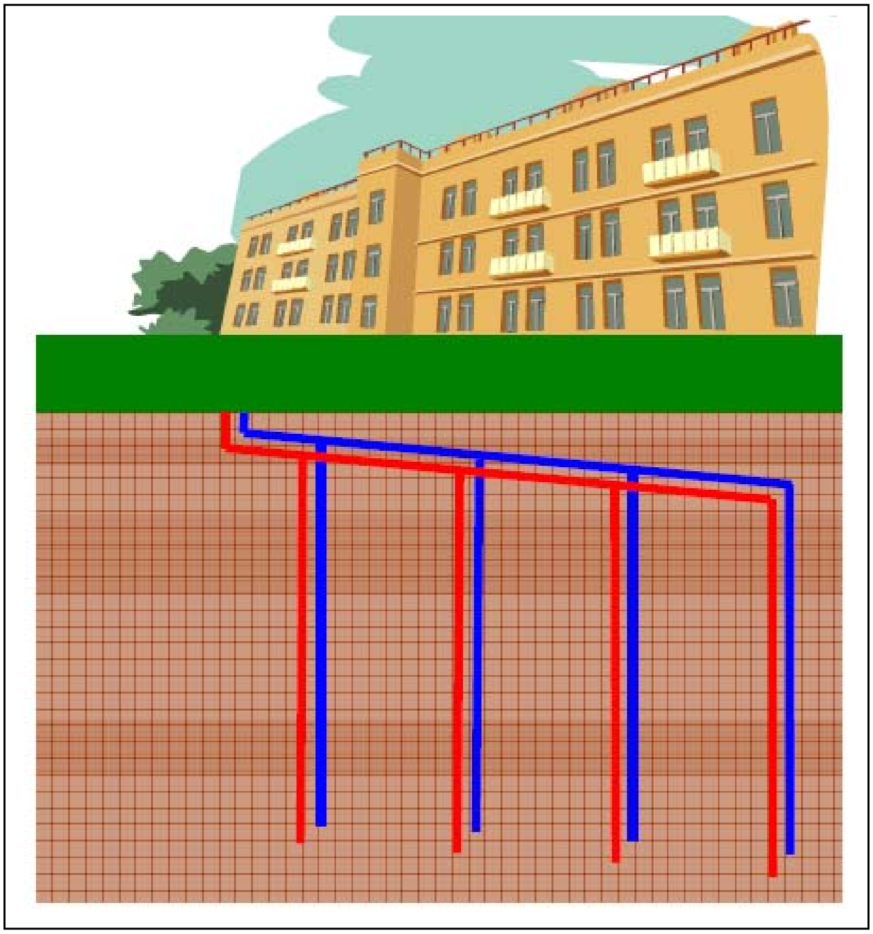
Ground Source Heat Pumps

Because the Ground Temperature is about 50 degrees F All Year Long



What is a Heat Pump?
Any mechanical refrigeration cycle is a heat pump. The alternate compression and vaporization of the refrigerant creates a warm and cold region. Regular air conditioning and refrigeration leverage this phenomenon by placing the cold region (a coil) indoors and the warm region (coil) outdoors - the heat from the house is literally 'pumped' outdoors and rejected.

A heat pump is a modified refrigeration unit that can redirect the flow of refrigerant on command. When the roles of outdoor and indoor coils are reversed, heat can be pumped inside. With this modification, the same equipment can be used to cool a house in summer and also heat it in winter.

A common heat pump application is an air-source heat pump, so named because it uses outside air as a source of heat in winter. The efficiency of air-source heat pumps is good at moderate temperatures but drops off quickly at lower temperatures. For this reason, air-source heat pump use is usually limited to mild climate regions.

The ground source heat pump has the unique advantage that the source of heat it sees in cold weather is not as cold as the air temperature at the surface. For this reason, heating efficiencies remain stable even at low temperatures for ground source heat pumps. When deep enough, the ground temperature is almost unaffected by surface temperature. It is not uncommon for ground temperature to be 55 degrees F when it is [-10] degrees F outside. So, if the heat pump concept is applied where there happens to be a warm source year round…..bingo! High efficiency happens. In fact, the efficiencies for a well-designed GSHP are remarkable. Heating and cooling system rating nomenclature varies by type. One set of units that can apply to all HVAC heat/cool systems is the ***Coefficient of Performance*** (COP). This is a unitless measure of heat output to heat input. The following are typical ratings for comparison. Higher numbers mean more efficiency.

The heating energy consumption of a GSHP is about one fourth that of a natural gas furnace, but the cost of the two energy sources is different. Btu-for-Btu, gas costs less than electric. The economics of operation vary by location and the relative difference between electric cost and fuel cost; however in many locations ***the cost of heating with a GSHP is usually less than half of the cost of heating with gas, even with the most efficient gas-fired heater available.***

HVAC System	Cooling COP	Heating COP
Ground Source Heat Pump with loop water temperature at 32 degrees F in heating season and 77 degrees F cooling season (EER-18 summer)	**5.2**	**4.0**
Air Source Heat Pump Summer: 95 degrees F outdoor temp, EER-12 Winter: 47 degrees F Winter: 17 degrees F Winter: 0 degrees F (all electric resistance)	3.5	3.7 2.5 1.0
High Efficiency Air Conditioner at 95 degrees F outdoor temp, EER-12	3.5	---
Water-cooled centrifugal chiller @ 0.55kW/ton	6.4	---
Electric resistance heating	---	1.0
Gas furnace or boiler at 80%e	---	0.8
Gas furnace at 95%e	---	0.95

The Ground Coupled Heat Exchanger – the Heart of a GSHP System
Of course, achieving these savings is not free. It requires an investment in the system that exchanges heat with the earth. Whether installed vertically or horizontally, it is a significant undertaking.

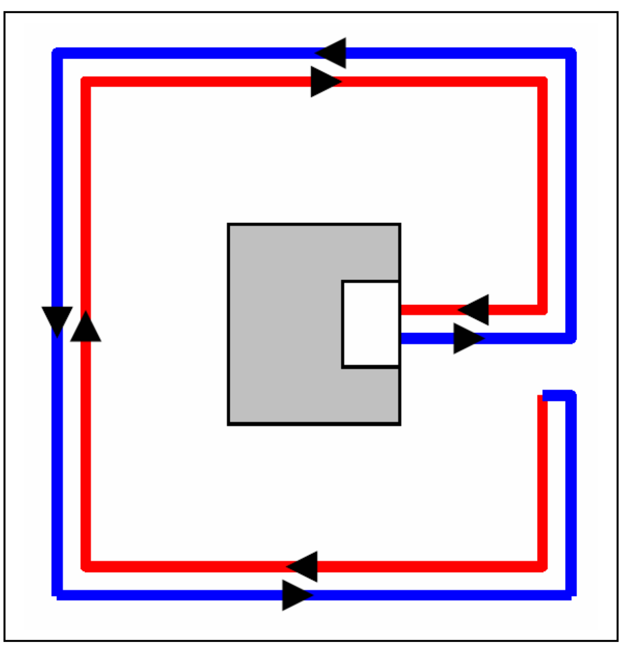
GSHP systems are part of a larger system classification known as Geothermal Heat Pumps. This refers to any heat pump that utilizes the earth temperature. This paper focuses on the specific group of heat pump applications that are coupled to the ground – Ground Source Heat Pumps (GSHP). Specifically, the heat exchange is between the circulating fluid and soil.

There is an unknown in any GSHP project and that is soil properties and drilling obstacles. Sometimes it's just bad/good luck. If soil conductivity happens to be good and drilling is favorable, it can be cost effective. In other locations, drilling is impractical and cost prohibitive. Usually the cost of a GSHP project includes some range of cost uncertainty for the excavation, unless soil conditions in that location is known.

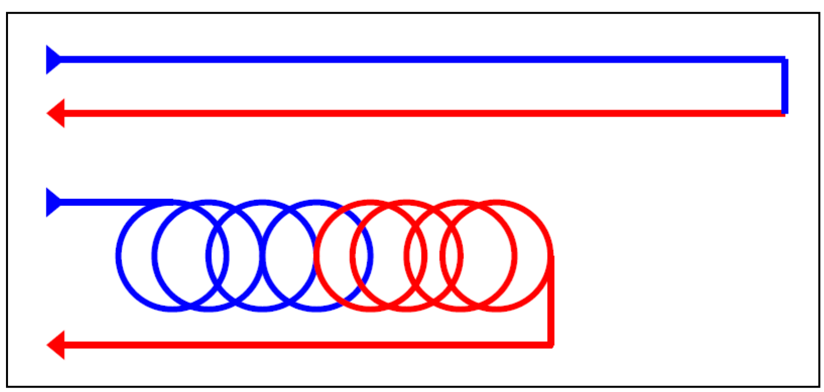
This picture at the top of this paper shows the classic ***vertical*** bore field. It takes about 3 bores per ton, at 300 feet depth. Soil properties, moisture content, depth, and spacing all come into play for vertical designs. Dry sand is about the worst for heat transfer and heat capacity. If soil conditions permit drilling this is the usual choice for larger systems since less property area is needed.

Without x-ray glasses, nobody knows for sure what's down there. Obviously if the heat exchange tubes pass through a cavity in the soil, little heat transfer benefit occurs in that air space. If the soil has high moisture content it will enhance the heat transfer effect, but will the soil always be wet? Or will months of cooling operation (rejecting heat into the soil) dry out the soil? If the design depends upon the benefit of being moist and it dries out over time, then what? This is an argument for soil testing and for very conservative designs. It is unlikely that the soil changes over time will cause the system to stop functioning, but it may well be that the efficiency is reduced if the soil isn't properly taken into account. Tip: once the property is dug up with all the heavy equipment, a few more tubes will not add much cost but can go a long way to long term sustained efficiency.

The ***horizontal*** concept loop field approach can work well for smaller systems in areas where digging deep is an issue. Avoid the temptation to install these shallow. Remember, the closer to the surface the more the surface temperature effect is felt and the greater the ground temperature swing will be – the efficiency of these systems depends upon the relative accuracy of the assumption that the ground temperature remains constant. A depth of 10-12 feet is suggested for optimal performance although systems have been installed in as little as 5 feet of depth. Through careful design, it is possible to counter the surface effect with a longer or wider array of tubing. Still, deeper is better. The ***slinky*** system increases the tube surface area by coiling, reducing the necessary excavation. The slinky arrangement can be horizontal or vertical, but is usually horizontal for practical reasons.



Horizontal Loop Field



Linear vs. Slinky Arrangement

Horizontal loop fields take up a lot of space. This is the size of a field to serve a 3-ton heat pump – about enough heating capacity for an average house. Without an abundance of property, horizontal fields are usually impractical for large commercial systems.

Other Heat Exchanger Variations

Not all locations are practical to install vertical or horizontal bore fields.
In addition to vertical bore fields and horizontal loop fields, heat pumps have been successfully used with other heat exchanger arrangements. These include:

- Lakes, with a submerged heat exchange loop or a pre-made metal heat exchanger coil
- Standing well / column system

The submerged heat exchanger takes advantage of an available body of water. The advantage is the reduced excavation costs. It is especially cost effective to install if there is a large abandoned well to utilize. Performance will depend on the stability of the water temperature throughout the year which, in turn, is dependent upon depth and volume of water. If water temperatures vary significantly, performance (efficiency) will suffer. Fouling is also a concern for the lake heat exchanger and provisions to clean it may be necessary. In some designs the heat exchanger performance depends upon the free flow of water over it – in these cases, provisions to keep it off the bottom and periodic cleaning may be necessary to maintain good performance.

The standing well / column method also has the advantage of reduced excavation costs. However this system is an "open system" which introduces new concerns. Any system that uses 'raw' (open system, un-treated) water instead of a sealed system with treated fluid will experience fouling and long term performance degradation. The term "fouling" is when minerals or debris coats a heat transfer surface; the result is a slowing of heat transfer and a loss of system performance and efficiency. Part of the functionality of a standing column system is the dependence upon natural stratification (warm fluid rises). If the particular well geometry doesn't create the desired separation between cold and warm fluid performance loss will result.

Quality Control
Ground Source Heat Pump systems are among the most energy efficient systems if working properly. The following will give some steps to take to help assure you get the most out of your GSHP system.

Certification. Quality begins with design and extends through construction. Formal certification programs are in place through the International Ground Source Heat Pump Association (IGSHPA). An excellent first step as a consumer is to require the designers and installers be certified by IGSHPA.

Design. Soil testing and computer modeling of the long term heat sink effects are key to a high confidence level for the system. Depending upon the area, the heat pump units may dominate in heating mode or cooling mode – and the soil temperature around the tubes in the ground will creep over time to colder or warmer temperature respectively. If there is a large imbalance, extra tubes can stave off the inevitable drift in temperature. In some commercial applications, called 'hybrid GSHP', there is an auxiliary cooling tower designed to reject some of the heat and bring the seasonal adding/subtracting of heat into the ground closer to a balance. The perfect scenario is an exact match between cooling and heating seasons; if that occurs the thermal performance of the ground loop or bore field will be stable over time. Design input also includes proper specification of grout (around the bore holes), piping and joints, heat pump equipment, pipe layout, balancing for even flow, etc.

Backup Resistance Heat. There may be a cost-saving suggestion to downsize the heat pumps and use backup resistive heaters. If the budget has run dry there may not be a choice, but a properly designed GSHP system will not require resistive heat.

Bore Field. All GSHP systems depend on the integrity of the bore field. After the bore field is covered with tons of dirt it is totally inaccessible. Thus, quality control of the bore field before covering it up is strongly recommended.

The Appendix has a list of technical suggestions for GSHP quality control.

To Learn More
How to Buy an Energy Efficient Ground Source Heat Pump, U.S. Department of Energy, Energy Efficiency and Renewable Energy, Federal Energy Management Program, http://www1.eere.energy.gov/femp/procurement/eep_groundsource_heatpumps.html

Ground Source Heat Pumps Applied to Commercial Buildings, Parker, S., Chapter 28, Energy Management Handbook, 7th ed., Fairmont Press.

Ground Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings, Kavanaugh, S. and Rafferty, K. 1997, American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), Atlanta Georgia.

International Ground Source Heat Pump Association (IGSHPA) certification program. www.igshpa.okstate.edu

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APPENDIX - Ground Source Heat Pump Quality Control Comments.

Quality Control

- Design by Certified GSHP designer strongly recommended.
- Installation by a Certified GSHP installer strongly recommended.
- An independent third party to verify all quality control measures is recommended.

General

- Load calculations required to show the system is not oversized.
- In situ soil testing is required for systems over 10 tons cooling capacity. In situ testing for smaller systems is optional; however the assumption of dry soil should be required without testing.
- Equipment rated per ISO-13256-1, suitable for operation with entering water temperatures ranging from 32-100 degF.
- No auxiliary electric resistance heating.
- De-rates for glycol.
- Heating **COP of 4.0** or higher at 32 degF entering water temp.
- Cooling efficiency of **17 EER** (not SEER) or higher at 77 degF water temp.
- Circulating pump transport energy ratio of 0.075 hp per ton or lower.
- Computer modeling of the long term performance of the bore field, to demonstrate that actual loop field performance and loop water temperatures will not exceed the range of 40-77 degF after 25 years of operation, to demonstrate sustainability.
- Specify equipment per ISO 13256-1 **ground loop 32-77 degrees F.**
- Require scroll compressors for extended life.

Ground Heat Exchanger

- Provide Load calculations and profile, to establish annual heat/cool sink rates and amounts.
- Provide GLHEPRO or equivalent software analysis to demonstrate the bore field performance and long-term temperature effects for steady state operation (min 20 years). The design loop field temperatures should be maintained within stated limits for 20 years minimum.
- Verify that energy consumption values are based on either worst case or account for the creeping temperature effect.
- In-situ test results (soil conductivity testing within the actual bore field location). If the soil is drier than assumed, or becomes drier over time, this can de-rate the soil heat transfer performance by up to 50%, with significant loss of efficiency. It is recommended that the bore field design presume soil is 'a notch' drier than in-situ testing indicates, to assure sustained performance. For example is soil is found to be 'heavy soil saturated' use design parameters for 'heavy soil damp' for a design margin of safety. If in-situ testing is not chosen, it is recommended that 'dry' soil conditions be assumed in loop field design, to be confident of long term performance.
- Most critical parameter of design is soil moisture content. Next is heat/cool profiles.
- If the heat/cool loads are imbalanced, consider a cooling tower and monitoring to level the loads. This can help to stabilize the loop field temperature (and system performance) over time.
- Size for use without electric heat.

- Bore field at least 50 ft from the building
- Use glycol. Use only PG to protect ground water.
- **Ground loop design to provide 32 min (winter), 77 max (summer) water temperatures after 20 years of service**.

Piping

- Piping material: PE 345434C (most common) , PE 355434C, or 345534C, SDR 11, 160 psi rated all sizes.
- Butt fusion, socket fusion, or electro fusion. No mechanical joints underground.
- All piping flows in turbulent regime, with Reynolds Number (Nre) 4000 or higher. Use tables corrected for glycol. Check closely if VFD's are used, and establish minimum flows. The turbulent nature of the water in the loop field will ensure proper heat transfer through the bore field tubing.
- Loop field spacing in the range of 10' – 20' centers.
- Pipe friction in the range of 1-3 ft/100 ft.
- Upsize headers to help balance parallel flow. Parallel branch loss should be 3x header loss to achieve +/- 15% balancing. E.g. for the loop field, 25% or less should be charged to the mains, and the rest should be the individual bore holes.
- Use reverse return piping where possible, for systems that tend to be self-balancing.
- Each parallel loop the same length for equal flow.
- Include air release provisions, including air separator.
- Each U-bend is worth 10 ft. equivalent pipe length.
- Max length of piping to achieve 10-13 ft w.c., based on water: ¾ inch (3 gpm 500 ft), 1 inch (3 gpm, 1500 ft) (4.5 gpm, 800 ft), 1-1/4 inch (7.5 gpm, 1200 ft), 1-1/2 inch (9gpm, 1500 ft), 2 inch (15 gpm, 2500 ft).
- To adjust the total piping head loss for antifreeze and water solutions at 25 degF, multiply the pressure loss values for plain water by 1.36 (20% pg).

Start-Up and Maintenance

- The #1 killer of GSHP systems is lack of proper flushing / cleaning / sterilizing / treating the water.
- Flush/air purge at least 2 ft per second. Unless sectioned off, this can amount to a large flow.

Rules of thumb

- Bore hole 300 ft per ton, twin tube bore
- A/C de-superheater 3500 Btuh per nominal ton of capacity (for domestic hot water).

Sizing considerations:
Since the same apparatus provides both heating and cooling, understanding the relative magnitude of heating and cooling demands are very important for equipment selection.

Generally a residential heat pump in Colorado will be sized for heating demand. Typical heating demand is about 25kBtu per 1000 SF. Typical cooling demand is 16 Btu/SF (750 SF/ton).

For example, a heat pump with 25 Btu/SF heating capacity at COP=4 will require 1.83kW per 1000 SF. This kW, at 0.7 kW/ton (EER-17) will provide 31 Btu/SF cooling capacity – resulting in over sizing during cooling season by almost a factor of two. So, for residential heat pumps, a 2-stage or 2-speed unit should be considered to avoid short cycling.

Commercial sizing may be balanced heavier in cooling than heating (modern office building), but really depends a lot on the ratio of envelope loads compared to internal loads, and the amount of outside air used. Load calculations are required to establish the maximum cooling and heating demands to determine equipment sizing, and the total seasonal heating and cooling demands on the loop field, to determine its long term performance.