TAPPING THE EARTH FOR CHEAP HEAT

If you think heat pumps aren't practical up North, it's time to look at closed-loop, earth-coupled heat pumps

by John Siegenthaler

In 1852 Lord Kelvin, an English physicist and engineer, proposed a novel way to heat houses: Extract heat from the outside air. The technology has come a long way since then, and heat pumps have become a major industry in the U.S.

With engineering improvements, the "air-to-air" technology envisioned by Lord Kelvin has become a practical, economically competitive way to heat and cool houses in moderate climates. Heat is absorbed from outside air in winter and delivered to the house via forced air ducting. In summer, the refrigeration cycle is reversed, with heat taken from inside the house and rejected outside.

But air-to-air systems are far less viable in the cold northern states. The coefficient of performance (COP) experienced during prolonged periods of sub-freezing outside air temperatures mandates some form of supplemental heating.

In all-electric systems, the supplemental heat is usually provided by electric strip heating elements mounted in the duct work near the discharge of the heat pump. During cold periods (20°F or lower), the strip heating provides the majority if not all of the heat to the building.

For a heat pump to function at a consistently high COP with predictable heating capacity, it must tap a stable source of free heat. The earth has long been recognized as such a source.

During the last five to ten years, the technology of extracting heat from the earth has improved, and several U.S. firms have begun developing a market for earth-coupled heat pump (ECHP) systems.

In cold climates, where outside air temperatures fall below practical limits for efficient operation of air-to-air systems, the temperature of the soil at a given depth and time of year can be estimated quite accurately.

Furthermore, although the soil temperature gradually decreases during the heating season, it is virtually immune to sudden air temperature changes at the surface (see Figure 1). Because of the stability and higher temperature of this heat source, the heating capacity of the pump is higher and more stable, minimizing or eliminating the need for a supplemental heat source.

Also, during the cooling season, earth-coupled heat pumps typically have a higher energy efficiency ratio (EER) because they reject heat to soil that is far cooler than the ambient air temperatures.

Closed Loop vs. Open Loop

Closed loop systems typically employ several hundred feet of buried thermoplastic pipe as the "earth loop heat exchanger." Water, or a mixture of water and antifreeze, is circulated through the buried pipe and the heat pump. Once filled and purged of all air, no fluid enters or leaves. Heat is transferred from the soil to the fluid across the wall of the buried pipe.

By contrast, an open loop system pumps water from a well, large pond, or lake. Residential systems will typically require a sustainable water supply ranging from six to twelve gallons per minute whenever the heat pump is operating. Then there must be an environmentally sound way to dispose of the water—either a re-injection well (if allowed under local codes) or a large pond or lake. Since closed loop systems recirculate the same fluid within the buried pipe, these enormous requirements for water supply and disposal capacity are eliminated.

Also, in an open loop system, water quality must be taken into account. Hardness and corrosion potential, for example, must be suitably low or heat exchanger fouling will eventually present a serious maintenance problem. In a properly designed closed loop system, the water chemistry is easily controlled in the absence of oxygen.

Creating the Loop

The type of earth pipe used for the closed loop system is of critical importance to its success and longevity. Only two types of thermoplastic are currently recommended: high density polyethylene and polybutylene. Both materials are available in a range of pipe sizes, and come in continuous coils up

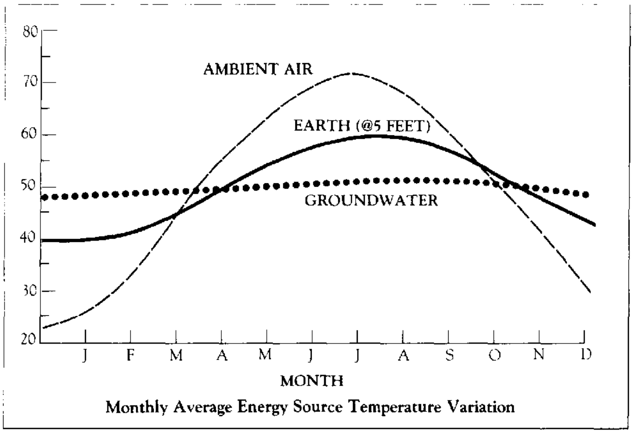


Figure 1. At a 5-foot depth, the temperature of the earth remains stable despite wide fluctuations of air temperatures on peak winter days.

to at least 500 feet in length. They can flex to accommodate the stresses imposed by variations in soil temperature and moisture content. PVC pipe does not have these qualities, and is not recommended.

Sections of pipe are joined by heat fusion processes. No threaded or clamped joints should be used in any buried portion of the loop.

Polyethylene pipe is joined with a process known as "butt fusion." Both ends are clamped into a butt fusion fixture. The ends are then trimmed absolutely square, and heated to approximately 500°F. The semi-molten ends are forced together and held until cool. The result is true molecular bonding, and the joint is actually stronger than the pipe itself. The butt fusion process, shown in photo, is easily learned and readily done in the field.

Polybutylene pipe is joined using "socket fusion." Fittings are used, and a fusion heating tool simultaneously heats both the outside surface of the pipe and the inside surface of the fitting. This is also an easy process to learn, and results in a very strong joint with a true molecular bond.

Never compromise the integrity of an earth loop by deviating from the established pipe fusion procedures. Also, regardless of the joining method used, all earth loop assemblies should be pressure tested prior to backfilling. When properly installed, an earth loop can last longer than the building.

The butt-fusion fixture shown here is the proper tool for joining polyethylene pipe for use in a ground loop.

Horizontal vs. Vertical Installations

There are several ways to bury an earth loop. Typically, the loop is classified as being either horizontal or vertical.

There are many possible configurations for a horizontal installation, including those illustrated in Figure 3.

Trenches are commonly dug using a backhoe or a chain trenching machine. A tractor mounted backhoe/front loader is often the preferred tool for horizontal earth coil installation since it is readily accessible in most locations and can handle a variety of soil conditions.

Figure 4 shows a typical vertical earth loop installation. A prefabricated U-bend is heat fused to the pipe to form a "bobbie pin" type assembly which can be inserted into boreholes ranging in diameter from 4 to 6 inches.

The hole is then refilled with the tailings from the hole or a mixture of fine sand. The piping assemblies are then manifolded together, at least 4 feet below the surface, and routed to the building via horizontal trenches. Since the bore hole is refilled, it does not need to be cased in steel.

In my experience, horizontal earth coil installation using a tractor mounted backhoe with a 2-foot-wide bucket is considerably less expensive than an equivalent vertical loop installation. With a 2-foot bucket, the four pipe square arrangement shown in Figure 2 is a good choice.

In my experience, a horizontal earth-coil installation using a backhoe is considerably less expensive than an equivalent vertical loop.

Creative Ways to Cut Costs

At new construction sites, other opportunities for burying the pipe may be available. For example, incorporating the earth loop into a cut/fill operation on a sloping site adds little if any extra cost for excavation.

If a long and sufficiently deep trench is needed for footing drainage lines, all or part of the earth loop might be installed at a different depth in the same trench. However, this is not recommended if the earth loop is designed—as some are—to freeze the soil immediately surrounding it during long periods of heat pump operation.

It's also possible in some cases to use an abandoned or "dry hole" well for a vertical earth coil installation. Keep in mind that the well must be refilled once the loop has been inserted.

When thinking about creative ways to bury the earth loop, two definite precautions are in order. Do not in any way attempt to directly cool a septic tank, and do not route the earth coil adjacent to drainage lines carrying surface or roof run-off water. In the latter case, near-freezing run-off water or melting snow could artificially lower the subsurface soil temperatures.

Rules of Thumb

When design options are evaluated, clients often ask how many feet of pipe the system will require and how deep the pipe will have to be buried. As usual, there are no definite answers without detailed analysis, but rules of thumb do exist.

Table 1 gives approximate earth loop lengths for both horizontal and vertical systems. This table assumes that fluid entering the heat pump will not be

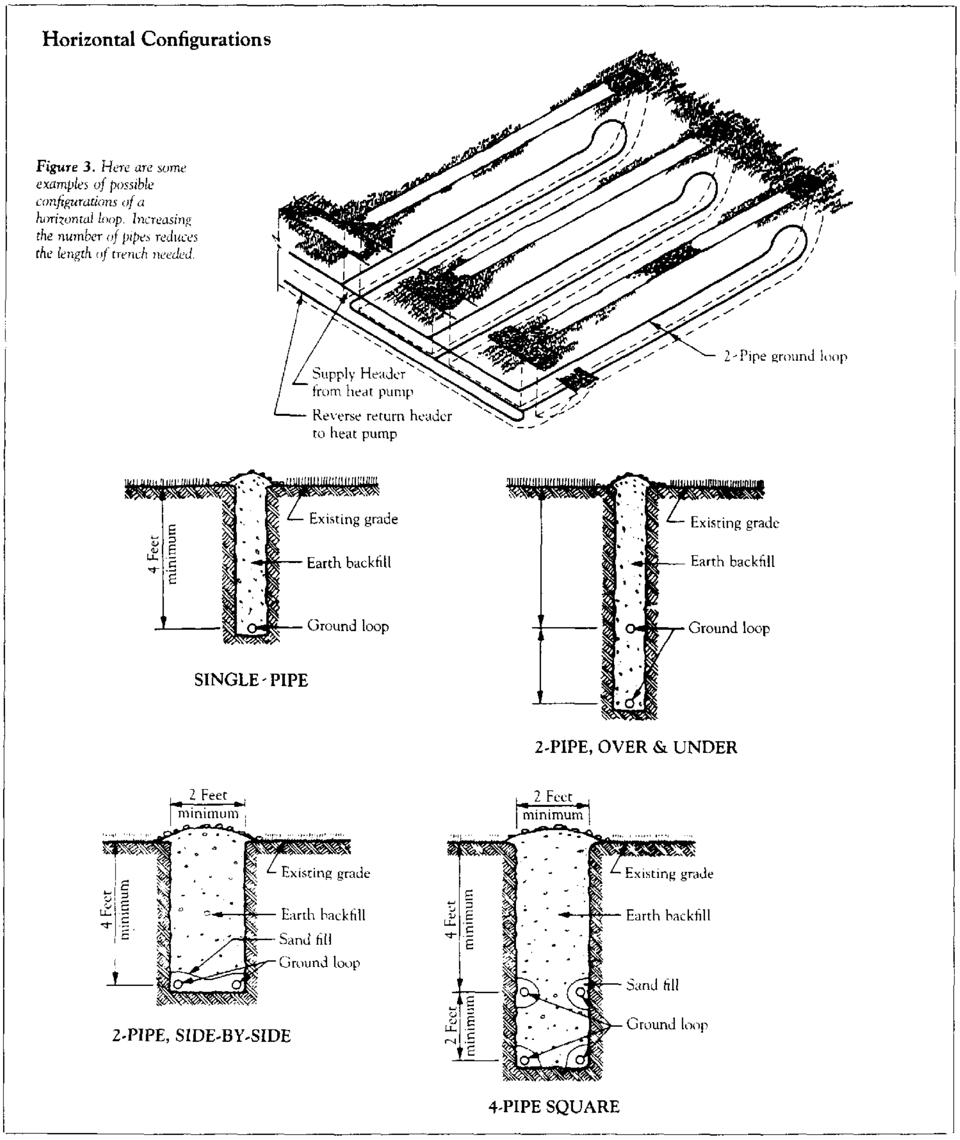


Figure 3. *Here are some examples of possible configurations of a horizontal loop. Increasing the number of pipes reduces the length of trench needed.*

A Heat Pump Primer

A heat pump follows the same principles as a household refrigerator, but on a bigger scale. It absorbs heat from one location and moves (pumps) it to another.

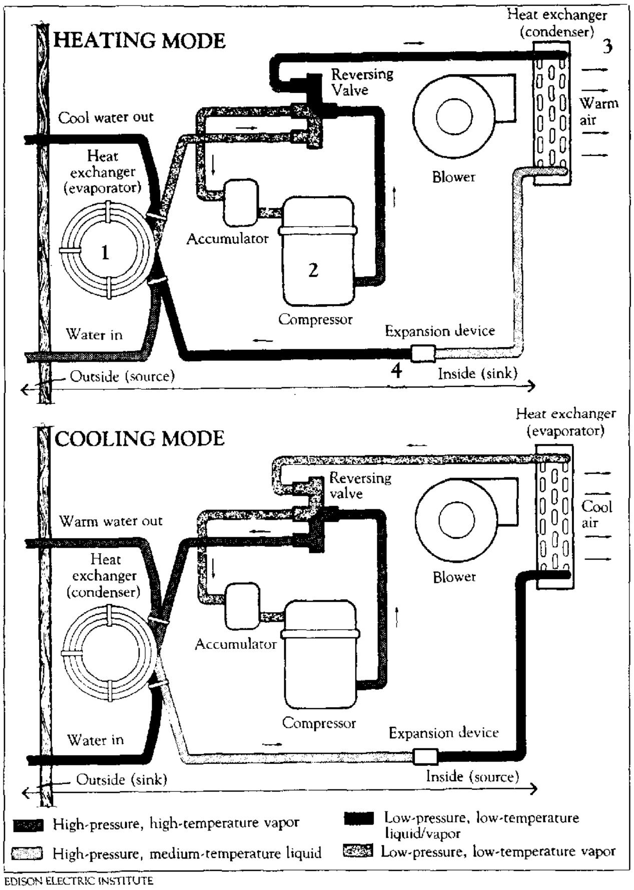
The heat may be absorbed from air or from water. The diagram below shows the main components of a water source heat pump, the kind that would be used in an earth-coupled system.

The heart of any heat pump system is the refrigeration circuit. This is a closed, pressurized piping loop through which a refrigerant compound (usually a fluorocarbon referred to as R-22) circulates.

The refrigerant cycle begins at the water-to-refrigerant heat exchanger (#1 on the diagram). Here, the refrigerant enters as a low-temperature, low-pressure liquid. At this low temperature, it absorbs heat from the water passing through the other circuit in the same heat exchanger.

This causes the refrigerant to boil (evaporate), although it remains relatively cool. It then passes through a reversing valve (described later) and an accumulator. If there are any small droplets that remain in liquid form, they are collected in the accumulator, so that they will not enter the compressor.

The refrigerant compressor (2) works much like an air compressor, greatly increasing the pressure and temperature of the refrigerant. The hot gas now flows to the refrigerant-to-air heat exchanger (3), where it gives up most of its heat to a stream



of air being blown across the heat exchanger surface.

The refrigerant, thus cooled, condenses back to a liquid state. Still under high pressure, the liquid refrigerant now enters an expansion device (4), which is commonly either a thermal expansion valve (TXV) or a capillary tube. This causes an immediate drop in pressure, which in turn lowers the temperature of the liquid refrigerant to begin the cycle again.

To convert the heat pump from a heating machine to a cooling machine, an electrically-activated reversing valve reverses the refrigerant flow. Heat is now absorbed at the refrigerant-to-air heat exchanger, and rejected to the stream of water passing through the water-to-refrigerant heat exchanger. This operating mode is shown in the lower portion of the diagram.

Air-to-air heat pumps follow a similar cycle, except the water-to-refrigerant heat exchanger (1) is replaced by an outdoor refrigerant-to-air heat exchanger. Air is pulled through the outside heat exchanger by a fan mounted in the unit.

This description is at best a primer. For a more complete technical description, the following publications are recommended:

Heat Pump Manual, by the Electric Power Research Institute; P.O. Box 10412; Palo Alto, CA 94303.

Heat Pump Systems, by Saur and Howell; John Wiley and Sons Publishing, Inc.; New York, NY. ■

allowed to fall below 25°F at any time. The numbers indicate feet per ton of heat capacity. For single pipe systems, the length of pipe required would be equal to the length of trench. For multiple pipe systems multiply the feet of trench by the number of pipes in the trench to get the total length of pipe needed.

Fundamental heat transfer principles mandate that the earth loop length increases if a higher loop temperature is wanted or if the loop is buried at a shallower depth. In no case should a system be designed without first determining the heating (and, if applicable, cooling) load of the building. Ballpark estimates are not acceptable. Oversized systems are costly and result in lower seasonal performance; undersized units will fail to maintain comfort and will require more auxiliary heating.

System Economics

When compared to other heating and cooling systems, closed loop earth-coupled systems are characterized by higher than average initial costs and lower operating costs. The true economic merit of any heating and cooling system must reflect the total owning and operating costs.

The so-called "life-cycle cost" method is useful in comparing ECHP to competing systems. However, bear in mind that the results are shaped by assumptions such as the annual inflation rate for heating fuels, and the accuracy of estimates of the installed cost of competing systems.

An accurate life-cycle cost estimate is very project specific. The results of one such analysis performed for the central New York State area are given in Table 2. The table uses "middle of the road" estimates for both cost and performance. All energy costs are factored in, including the earth loop circulator, blower, and auxiliary electric resistance heat. The analysis assumes that all systems were financed as part of a 30-year fixed mortgage at 10 percent plus 1.5 points. For simplicity, all fuel costs are inflated at 6 percent per year.

In this specific analysis, after only one year of operation the ECHP has a lower total cost than electric resistance heat or an air-to-air system. It becomes less costly than the oil furnace after seven years. Note that the savings would continue to grow during each subsequent year of operation.

Another factor to consider: For a typical family of four, domestic hot water adds another 15 percent to the total heating and cooling load. The savings associated with the ECHP become even more pronounced if it handles hot water

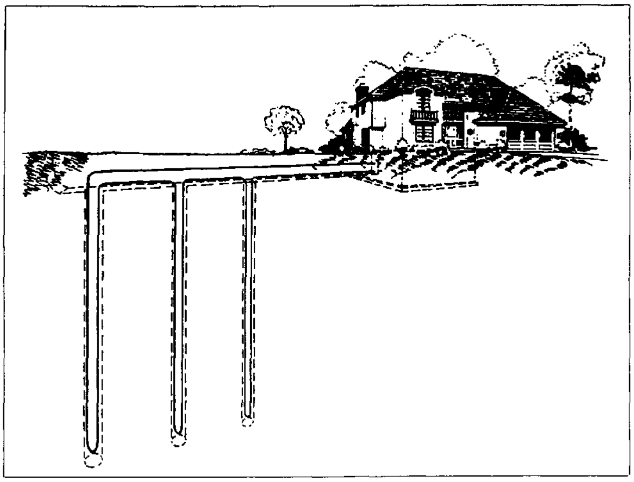


Figure 4. *A typical configuration for a vertical loop.*

Table 1
Earth Loop Sizing
(Rules of Thumb)

The following table shows the length of trench, or depth of borehole, needed per ton (12,000 Btus per hour) of heating capacity. The numbers should be multiplied by the tons of heating capacity needed. An average new house in upstate New York, for example, may require 2.5 to 3 tons. The figures assume that the temperature of the fluid entering the pump will not fall below 25°F. For multiple pipe systems, multiply the feet of trench by the number of pipes to get the total length of pipe.

Configuration	Trench Feet For Each Nominal Heat Ton, by Soil Type			
	Heavy Damp	Heavy Dry	Light Damp	Light Dry
Horizontal—One Pipe	353	405	438	729
Horizontal—Two Pipe (side by side)	216	251	271	445
Horizontal—Two Pipe (over/under)	218	253	274	450
Horizontal—Four Pipe Square	144	170	183	298

	Bore Feet For Each Nominal Heat Ton, by Soil Type	
	Dense Rock	Ordinary Rock
Vertical	135	183

in addition to heating and cooling.

Other Benefits

Other benefits of a typical ECHP system are difficult or impossible to quantify. They include the following:

- There is no visible outside equipment, and no outdoor operating noise.
- There is a long expected system life.
- The fire risk is low, and insurance' rates may be reduced because there is no combustion or on-site fuel storage.
- The non-combustive nature of the system means that no air infiltration is induced by the heat pump.
- Maintenance is generally limited to periodically changing the air filter on a forced air type system.
- A single system can meet the heating load, cooling load, and with a relatively inexpensive option, the domestic water heating load of the residence.
- Possible additional cost savings can be realized from time-of-use electric rate structures offered by some utilities.

Summary

Lord Kelvin's ideas have undergone a lot of refinement in the last 136 years. But until recently, heat pumps have not been considered a practical alternative in cold climates.

That limitation has been overcome by improvements in closed loop ECHP systems, which take advantage of the stable and moderate temperature of the earth.

Modern pipe materials and joining methods help insure reliable earth loops, with long life expectancy. Operating cost savings can quickly amortize the higher initial cost. Closed loop earth-coupled heat pump systems represent one of the highest performing heating and cooling systems available today. ■

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Table 2
Economic Comparisons

This table estimates (in simplified form) life-cycle costs of various heating systems for an average residence in central New York State. "Middle-of-the-road" cost estimates are used, and fuel consumption estimates are based on seasonal performance. This analysis assumes all systems were financed as part of a 30-year fixed rate mortgage and that all fuel costs inflate by 6 percent per year.

System Description	Installed Cost	1st Year Energy Cost	15 Year Cost To Own & Operate
Electric Baseboard, No Cooling	$1,550	$1,321	$33,213
Electric Furnace, 2.5 ton split system A/C	$5,080	$1,407	$40,840
Air-To-Air Heat Pump, Electric Aux. Heat	$5,000	$867	$28,134
Closed Loop ECHP, Electric Aux. Heat	$7,700	$537	$24,756
Oil Furnace, 2.5 ton split system A/C	$5,430	$698	$25,564

MORE INFORMATION

For additional information on earth loop piping materials contact:

Central Plastics Co.
Box 3129
Shawnee, OK 74801
800/654-3872

McElroy Manufacturing Co.
P.O. Box 580550
Tulsa, OK 74158-0550
918/836-8611

Orangeburg Industries, Inc.
946 Riverside Dr.
Asheville, NC 28804
800/438-5851

Vanguard Plastics, Inc.
831 N. Vanguard St.
McPherson, KS 67460
316/241-6369

For additional information on ECHP systems contact:

ASEA Cantherm
10300 Henri-Bourassa Blvd. West
Montreal, Quebec H4S 1N6
514/332-5350

Bard Manufacturing Co.
P.O. Box 607
Byran, OH 43506

Command-Air Corp.
P.O. Box 7916
Waco, TX 76714
817/840-3244

FHP Manufacturing
601 N.W. 65th Court
Fort Lauderdale, FL 33309
305/776-5471

Friedrich-ClimateMaster Div.
2007 Beechgrove Place
Utica, NY 13501
315/724-7111

GeoSystems, Inc.
3623 North Park Drive
Stillwater, OK 74075
405/372-6851

Heat Controller, Inc.
1900 Wellworth
Jackson, MI 49203

The International Ground Source Heat Pump Association
P.O. Box 1688
Stillwater, OK 74076-1688
405/624-5175

Mammoth Div. of Nortek
341 E. 7th St.
Holland, MI 49423
612/559-2711

Nepco-Hydroheat
P.O. Box 331
Monroeville, PA 15146
412/856-5440

Thermal Energy Transfer Corp. (TETCO)
1290 U.S. Route 42N
Delaware, OH 43015
800/GO-TETCO

WaterFurnace International
4307 Arden Drive
Fort Wayne, IN 46804
219/432-5667