Using the Earth's HEAT

by Sam Johnston

Courtesy Terraclime Geothermal (2)

Where does the heating energy come from for this home? Underground—where the constant temperature of the earth is absorbed and transferred to heat or cool the home.

Ground-source heat pumps use the stable temperature of the ground to heat, cool, and provide hot water for homes and businesses.

Gary Prior, an avid follower of renewable energy, decided to tap into this source for both philosophical and economic reasons. His family reduced its annual space and water heating expenses from $3,300 to less than $600. The 3-ton system also provides central air-conditioning and dehumidification that the home did not have previously.

How it Works

Ground-source heat pumps (GSHPs; sometimes termed "geothermal" by the heat pump industry) take advantage of the earth's steady subsurface temperature year-round. No matter if you are in Alaska or Arizona, the temperature 6 feet underground remains fairly constant. In New England, for instance, the earth's subsurface temperature is between 52 and 54°F. If you've ever gone into a cave on a warm day, you've probably noticed that the cave temperature is much cooler than outside. When the weather is cool, that same cave would be warmer than the outside air.

GSHPs use heat-transfer fluids (refrigerants) that have a low boiling temperature, so they can easily change from liquid to vapor and back again, transferring the energy from, or to, the earth's subsurface. Pipes (called a loop) drilled or buried in the ground circulate the refrigerants to transfer the heat in the ground to the heat pump. There, the heat is extracted from vaporized refrigerants and sent to a heat

Drilling vertical wells for heat pump systems takes little room and has little impact on the landscaping.

exchanger or air handler to heat water and/or air, which is then used to heat the house, either via a hydronic system or fan-forced, ducted system (see the "Distributing the Energy" sidebar). This process is reversed to cool the house, dumping excess interior heat into the ground.

In extreme weather—either very hot or very cold—a backup system may be needed to supplement the heating or cooling. However, with a properly sized system, most owners of GSHPs rarely turn to supplemental heating or cooling.

Heat Pump Variations

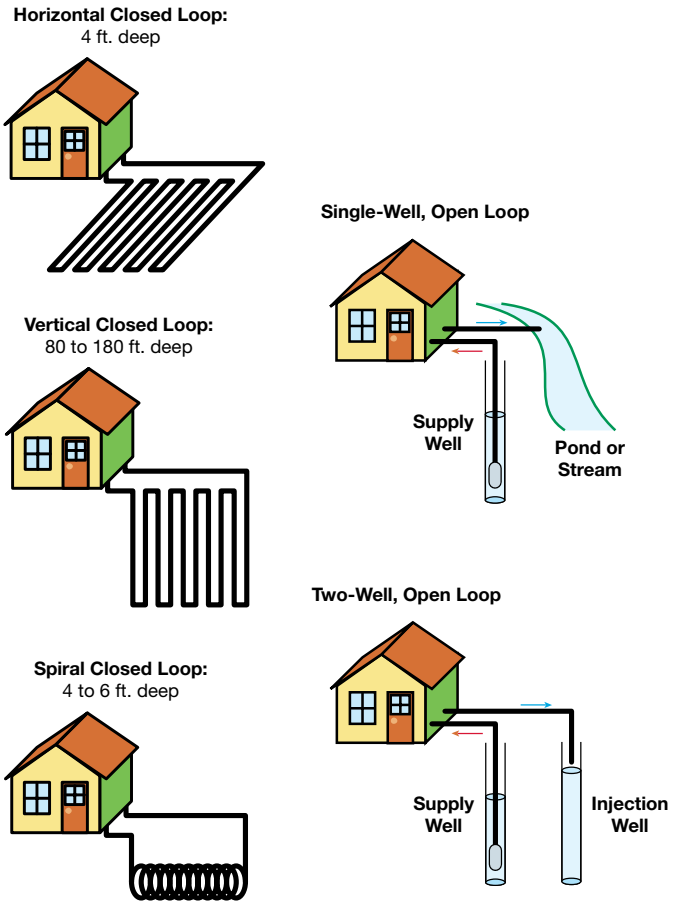
GSHPs use fluids to either directly or indirectly cause a refrigerant to change its state—that is, change from a liquid to a gas (taking on heat from the earth) or from a gas to a liquid (giving heat back to the earth)—similar to how a refrigerator works. These heat-transfer fluids (refrigerants) have low boiling temperatures. GSHP systems are either closed- or open-loop. Closed-loop systems typically circulate a propylene glycol and water solution through pipes in the ground and to the heat exchanger. There are several variations of closed-loop systems which differ in the orientation of pipes to the ground: vertical and horizontal (trenched, pit, and wide trench slinky).

Open-loop systems, nicknamed "pump 'n' dumps," use a body of water, usually a well or a pond, as the heat source and heat sink. The pond or well's water is circulated through the heat exchanger and then dumped back into the same water source. One type of open-loop system is the standing column well, where cold water is pumped from the bottom of a deep rock well into a heat pump, and then returned warmer to the top of the well, where, as it diffuses, the water returns to its original temperature.

Closed- vs. Open-Loop Heat Pump Systems

System	Pros	Cons
Closed-loop	• Can be installed almost anywhere • Fewer maintenance issues • Less temperamental	• Earth is not as good of a conductor • Less energy per foot of loop
Open-loop	• More energy per foot of loop • Water is a better conductor of energy than earth	• More maintenance issues • Could have local environmental risks • Requires lake or well nearby • More complex

Ground-Source Heat Pumps



Making the Switch

Before installing their GSHP, the Priors' 1975, 2,100-square-foot home relied on fuel oil for space and water heating. A heat pump was a good solution to both stabilize energy costs and decrease the family's reliance on non-renewable resources.

Once the Priors decided to make the switch, their home's envelope was assessed for ways to increase the home's efficiency and heat retention. The assessment encouraged them to add insulation in the attic. Additionally, they had their ducts inspected, and found they could upgrade their system to move air more efficiently, thus decreasing the size of the heat pump needed.

The entire heat-pump installation—digging and drilling for the loops—took two days. The drilling process includes:

Determining bore pattern. The drilling must be strategically laid out to avoid obstacles such as septic systems, utility lines, property boundaries, and boulders.

Drilling. Most GSHP installers hire contractors to drill according to specifications. When choosing a company to install your GSHP, ask about its relationship with drillers.

Fill and rough grade. After the ground loop is laid, the ground is filled and leveled back to original.

After drilling, a team of heat pump installers put in the air handler and GSHP in about three days.

Comparing Heaters' Fuel Costs

Fuel	Fuel Unit	Price Per Fuel Unit*	Heat Content Per Fuel Unit (Btu)	Fuel Price Per Million Btu	Heating Appliance	Type of Efficiency Rating	Efficiency Rating or Estimate	Approx. Efficiency	Fuel Cost Per Million Btu
Fuel oil (#2)	Gal.	$2.360	138,690	$17.02	Furnace or boiler	AFUE	78.0	78%	$21.82
Electricity	kWh	0.116	3,412	34.00	Furnace or boiler	Estimate	98.0	98%	34.69
					Air-source heat pump	HSPF	7.7	226%	15.06
					Ground-source heat pump	COP	3.3	330%	10.30
					Baseboard/room heater	Estimate	100.0	100%	34.00
Natural gas	Therm	1.230	100,000	12.30	Furnace or boiler	AFUE	78.0	78%	15.77
					Room heater (vented)	AFUE	65.0	65%	18.92
					Room heater (unvented)	Estimate	100.0	100%	12.30

Courtesy of the U.S. Energy Information Administration; * U.S. average

Open-loop systems tend to be more complicated than closed loops. One perception about open-loop systems is that they increase the temperature of the water source, affecting plant and animal life. This usually isn't an issue because of the minimal differences in temperature and the size of the water body. A bigger concern is the plants and animals themselves—open-loop systems often have maintenance issues with biologic and particulate infiltration. Open-loop systems are more regulated and often require extensive permitting.

The digging and drilling process depends on the type of system installed. Many closed-loop systems only disturb an 8- to 10-foot-square parcel of land. Other types of systems vary in the amount of disturbed yard. With the exception of extremely sandy soil conditions (poor heat conductivity), the type of soil is not a consideration for the effectiveness of a system. However, some soil types (such as extremely rocky) can affect the drilling process.

How It Compares

When deciding on space and water heating systems, homeowners must weigh the cost and energy usage. The actual savings from switching to a GSHP depends on the type of fuel previously used, the location, the weather, and the price of electricity.

Compared to conventional heating-oil systems, GSHPs can cut fuel costs by 50 to 80%. Heating oil is most common in the Northeast—the U.S. Energy Information Agency (EIA) states that of the 8.1 million households that use heating

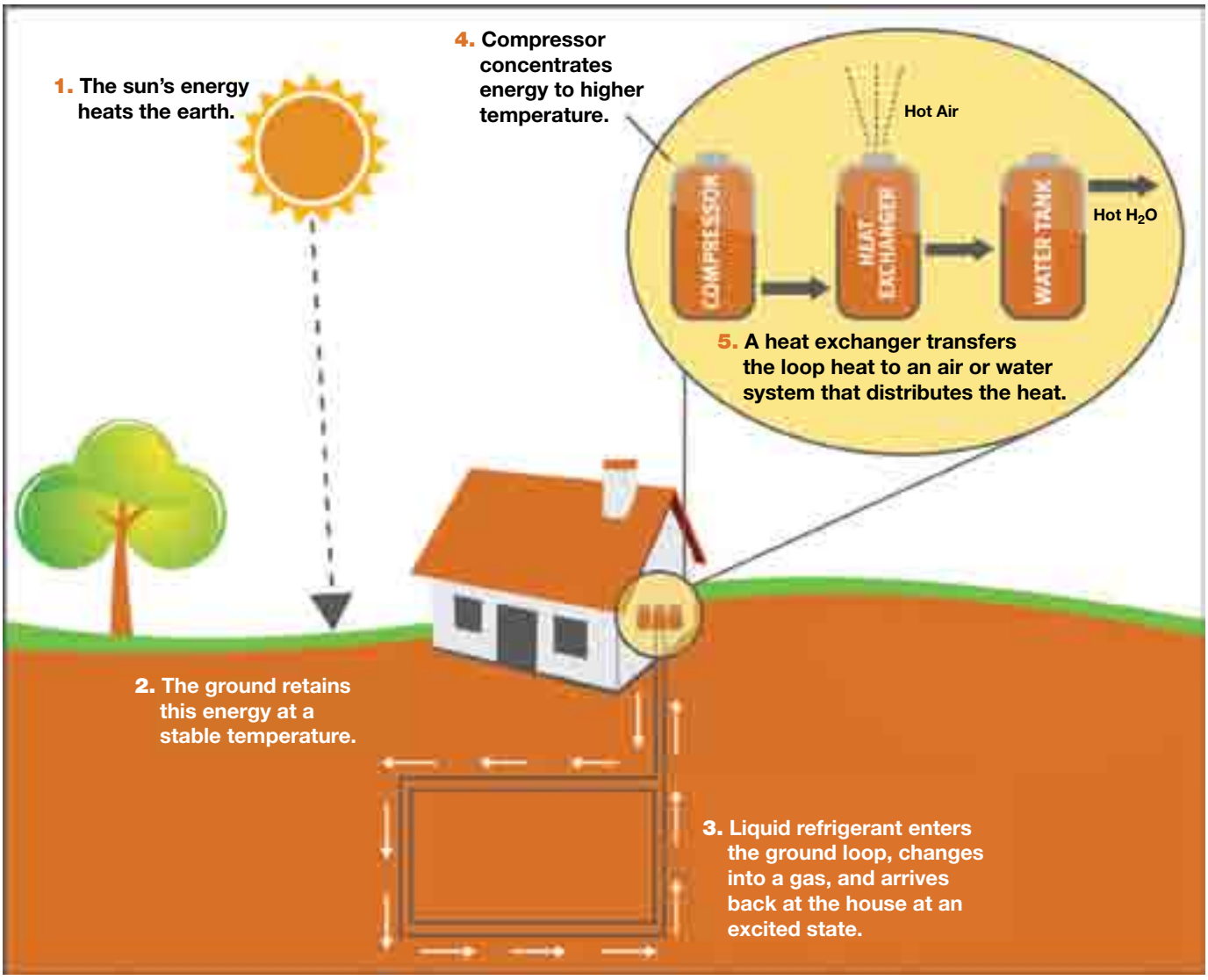
The ground loop, exiting the basement and entering the ground. Notice the snow—ground-source heat pump systems can be installed in almost any climate.

Courtesy Terraclime Geothermal

Sizing a System

The capacity of a heat pump system is measured in tons (1 ton of heat is 12,000 Btu/hr. or 3.5 kilowatts). A GSHP system costs $5,000 to $12,000 a ton, depending upon conditions of the home, especially ducting requirements. Insulation and weatherization are especially important considerations. If your home is poorly insulated, and has leaky windows and doors, improve those before getting an estimate for a new energy system. Most efficiency measures will be cheaper than the cost of a GSHP sized to make up for the inefficiencies.

With a return on investment of approximately three to five years, the Priors have gained independence from volatile oil prices and have a reliable system that will provide heating, cooling, and hot water for years to come.



Courtesy Terraclime Geothermal

oil, roughly 78% are in the Northeast. Besides being a non-renewable fuel, heating oil emissions are linked to poor air quality and resulting health issues, according to an Environmental Defense Fund study.

Heating oil systems make heat pumps a very attractive alternative, but how do they compare to cleaner, cheaper natural gas? Slightly more than half of the homes in the United States use natural gas as their heating fuel. When compared to electricity, the prices of both fuel oil and natural gas are more volatile, so knowing annual averages can help predict an accurate payback to see if the investment is worthwhile financially.

Heat pumps run on electricity only and can increase electric bills when switching from fossil fuel. The Priors' electric bill increased by almost $50 on average per month (see "Making the Switch" sidebar). During the heating/cooling seasons when the GSHP is working the most, the typical draw is 1,000 to 5,000 watts for a 1.5- to 6-ton system. Systems are usually designed for a 50% duty cycle.

In-ground view of a copper tubing ground loop.

Courtesy Terraclime Geothermal

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The inner components of a ground-source heat pump.

Inside the air handler (aka "air coil"), which is analogous to a car's cooling radiator coil.

An air handler for a GSHP can be added to an existing central heating system.

Heat pump systems are easily mixed with other energy solutions (hybrid systems). Heat pump and solar hot water systems complement each other. The GSHP can augment water heating, while also heating or cooling the home. Alternatively, one could route the solar-heated hot water from the roof to the ground loop to increase the thermal conductivity factor (aka, k-factor) of the looped system.

GSHPs compare favorably to traditional heating systems, especially in terms of system durability and longevity, and maintenance. A typical heat pump system lasts about 25 years and requires minimal maintenance. "All I have to do is change the air filters every six months," says Gary Prior, "much less work than writing a check to the oil company each month."

System Economics

Given volatile oil prices and an inefficient 30-year-old furnace, the Priors recognized a GSHP as an opportunity to save energy and gain freedom from oil prices. During the final winter the Priors bought fuel oil, oil prices topped $3.85 a gallon—the year that saw the largest single-year spike in oil prices. The relatively stable energy costs of a GSHP offered the Priors, who are near retirement age, some economic peace of mind.

web extra

Use the EIA Excel spreadsheet to compute your own energy and cost savings. Download it at www.eia.doe.gov/neic/experts/heatcalc.xls

Distributing the Energy

How the heat and cooling energy of a GSHP system is distributed is important to the system's efficiency. There are two main methods of distribution:

- **Hydronic radiant floor heat** is the most efficient distribution method. This strategy routes a heated fluid (water or a glycol solution) through pipes under or in the flooring. Objects near the floor are warmed first with minimal heat lost toward the ceiling. This option is more expensive than the others, and is limited to heating.
- **Hydronic radiators** work similarly to radiant flooring, and do not usually require the high temperatures (180°F or higher) of baseboard and steam radiators.
- **Forced-air** systems, which use a blower to push air through ducts and vents, are fairly common distribution method. This can be used for both heating and cooling. A second method of ducting uses high-velocity air flowing through small, flexible tubing about 2 inches in diameter instead of normal 6-inch ducting. Instead of being in the walls, high-velocity ducting is attached to the wall. This distribution method is a great option for historic homes and homes with solid walls (such as log cabins) where ducting cannot be installed in the walls. However, high-velocity systems tend to be noisier and must be maintained to prevent leaking air, which can cause noise.

Courtesy Terraclime Geothermal

Two (of four) hot water exchangers and a water storage tank make up this hydronic heating system.

In addition to saving money on their bills, the Priors benefited from both federal and state incentive programs, which offset their initial investment of approximately $29,000. For 2008, when the system was completed, the Priors received the maximum federal tax credit of $2,000—the cap for the 30% credit. As of January 2009, the cap has been eliminated, so homes like the Prior's could now receive the entire 30% federal tax credit.

The utility-based Connecticut Energy Efficiency Fund rebated $500 per ton, or $1,500, for the Prior's system. Since then, the Connecticut Clean Energy Fund added an American Recovery and Reinvestment Act of 2009 rebate that awards qualified Connecticut homeowners $2,000 per ton for retrofit projects, up to $12,000.

A GSHP system's financial benefit hinges primarily on the relative costs of electricity and fuels, which vary depending on the time of year and region. These systems typically have lower operational costs than most. Homeowners may save 20 to 60% annually on utilities by using a GSHP. Check with your local government and utility for incentives and grants to offset the initial system's cost.

Access

Samuel E. Johnston (sjohnston@terraclimegeo.com) has more than 30 years of experience in data acquisition and control, and energy management systems, including GSHPs. He works for Terraclime Geothermal, determining the marketability of ground-source heat pumps. He performs energy analyses to assess, design, and optimize the performance of energy systems.