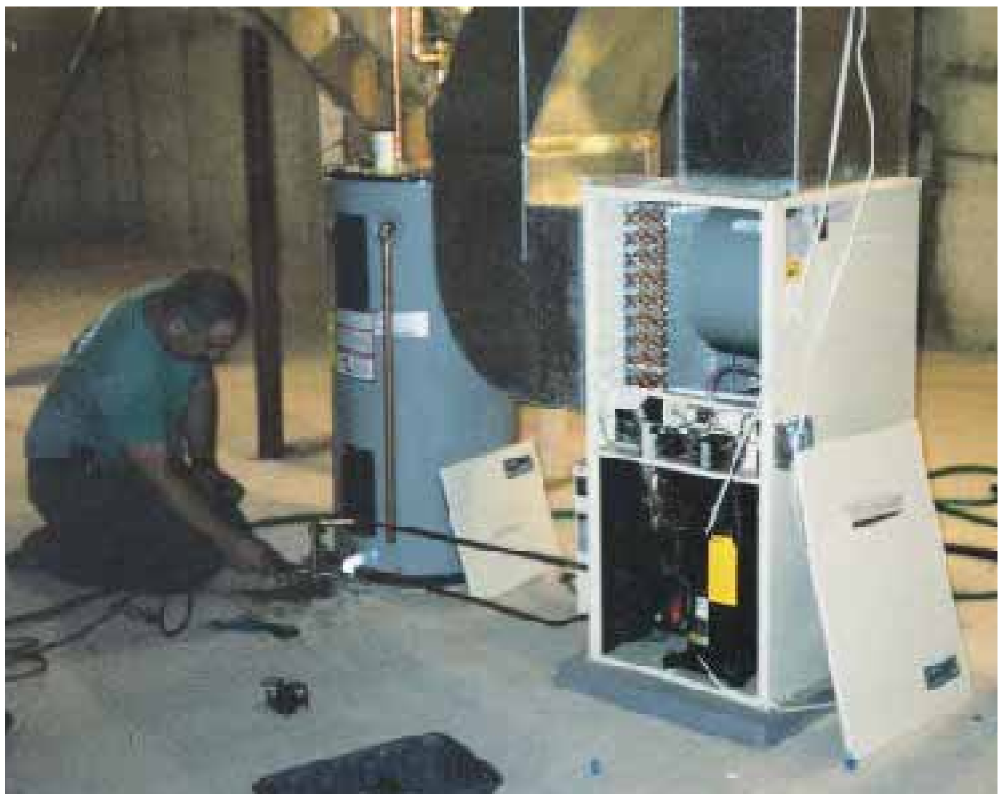
A BUILDER'S GUIDE TO Geothermal Heat Pumps

If designed and installed properly, a ground-source heat pump can provide comfortable, economical heating and air conditioning in many parts of the U.S.



MIKE GUERTIN

A ground-source heat pump is usually located indoors, where it's more protected from the weather than an air-source heat pump. This installation includes a desuperheater, which helps meet the demand for domestic hot water when the heat pump is running.

by Bruce Harley

I'm standing in a cramped attic in a one-year-old house, trying to discover the problem with the ground-source heat pump in front of me. As an engineer who tests dozens of heat pumps each year, I often get called in to troubleshoot problems no one else is able to solve.

Within a few minutes, I determine that one of the two compressors in this two-speed heat pump has shut down. I also discover that the return duct is undersized, causing extremely low air flow, and the supply duct to one particularly cold room is losing more than half its air through leaks into the attic.

These discoveries explain the tale of woe the homeowners recited to me over the phone. It began with the heat pump contractor who installed the unit in an uninsulated attic, contrary to the manufacturer's recommendations. After the water coil on the heat pump froze, flooding the garage ceiling, the contractor cut a small hole in the supply duct to try to warm up the attic, and attempted to repair the leak. He didn't realize, however, that the repair blocked the water flow through the coil, which soon caused the compressor to shut down.

In the meantime, the owners insulated the attic area to prevent future freeze-ups, but they were surprised to see that their electric bills skyrocketed. After several months of high utility bills, they again called the contractor, who came and pulled the fuse on the electric backup heat. But he didn't notice the shut-down compressor which, by failing to produce any heat, had been the reason the electric heat was kicking in.

Of course, with the resistance heat turned off, the upstairs zone was now too cold. So just a week before I arrived, the desperate owners had called in a different contractor, who taped up the hole in the supply duct and turned the resistance heat back on. But he also failed to notice that half the machine was shut down.

This case is not typical of heat pump installations, but it does illustrate how an inadequate understanding of how heat pumps work can make simple problems worse. If you're planning your first heat pump installation, it's important to have a good understanding of geothermal principles, because these systems are less forgiving of certain installation errors than conventional hvac systems.

Geothermal Options

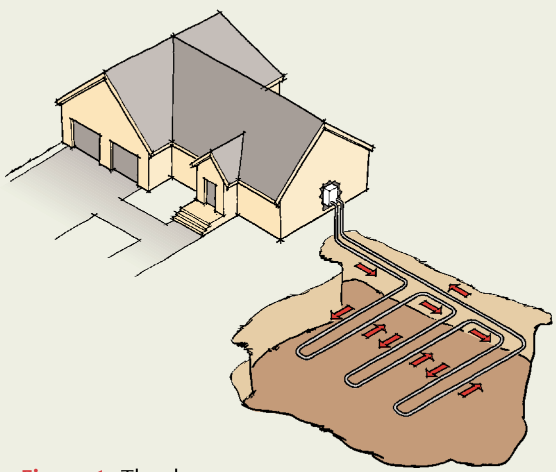
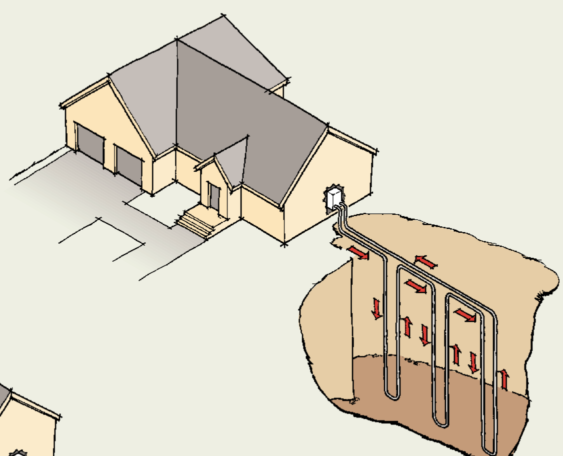
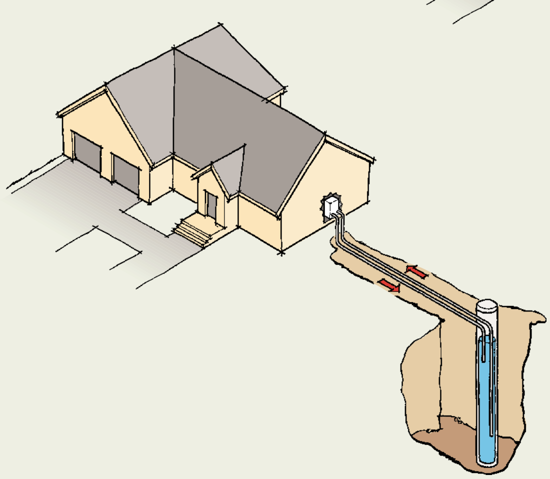


Figure 1. The three most common types of geothermal loops are horizontal closed loops, installed in trenches; vertical closed loops, installed in bore holes; and open loops, which use well water.





Heat Pump Basics

A heat pump is basically an air conditioner that can be reversed. In the summer, it moves heat out of the house to provide air conditioning, and in the winter it moves heat into the house to provide heating. *Air-source heat pumps* use an outdoor coil, just like the coil in a standard central air conditioner, to move heat to or from the outdoor air. A *geothermal heat pump* uses a water well or a buried loop of pipe to extract heat from the soil to heat a building, and to deliver heat back to the ground for cooling. Because the ground is so much warmer than outdoor air in winter, and so much cooler in the summer, geothermal systems are much more efficient than standard heat pumps and air conditioners. Geothermal systems that use a buried loop are called "closed-loop" systems, and those that use well water are referred to as "open loop" (see Figure 1).

Geothermal Economics

The cost of the ground loop makes a geothermal system more expensive to install than an air-source heat pump or a standard furnace with central air conditioning. However, the investment can pay for itself in lower utility bills. The details vary by locale, but here are some general factors that affect the payback:

- ***Electricity prices.*** Low electric rates favor geothermal heating systems. In areas of the country with higher electric rates, such as New England, oil or gas heating may be cheaper than geothermal heating. However, geothermal cooling will always be cheaper to operate than standard air conditioning, and higher electric rates will just speed up the payback.
- ***Cooling loads.*** Homes in climates with low annual air conditioning loads have less available savings from which to pay back the initial investment.

- ***Cost of other heating fuels.*** The higher the cost of oil, natural gas, or propane, the more likely that geothermal will be competitive.
- ***Availability of rebates.*** In some parts of the country, utility rebates reduce the up-front cost. If the rebates are generous, they may reduce the payback time to zero.
- ***House size.*** Larger homes have bigger budgets to absorb the initial cost, and higher annual heating and cooling loads to speed up payback times.
- ***Availability of installers.*** The cost of installing a ground loop varies considerably, depending on the local availability of experienced installers.
- ***Ease of excavation.*** The cost of a closed-loop system will be lower in soil that can be easily excavated with a trencher. For an open-loop system, a ready supply of groundwater can result in lower well drilling costs.

BUCK TAYLOR

Figure 2. After a backhoe digs a 5-foot-deep trench, two parallel polyethylene pipes are laid for one section of a horizontal ground loop.

The extra cost to install a geothermal system, compared with a high-efficiency furnace and central air conditioner, can vary from $2,000 to $15,000 per house, depending on many of these factors. These guidelines are by no means hard and fast rules; in New England where I live, most of these factors are not favorable to geothermal, and yet I've still seen many sensible and cost-effective installations.

Closed-Loop Systems

A closed loop consists of buried polyethylene or polybutylene pipe containing water or antifreeze solution, which is circulated by means of a small pump. It can be either a *horizontal ground loop*, installed in a trench or excavated area (Figure 2), or a *vertical ground loop*, installed in a drilled bore hole (Figure 3). Each bore hole in a vertical loop receives a U-shaped length of pipe, which is grouted in place (Figure 4, next page).

Closed-loop systems are usually more expensive to install than open-loop systems. Pumping costs are lower, however, because there is no need to raise up deep well water.

Figure 3. A well driller prepares to dig the bore holes for a vertical ground loop. On this job there were four 200-foot bore holes, each containing 400 feet of polyethylene pipe.

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The following details are critical when installing a closed-loop system:

Proper loop sizing. If a loop is too small, it can cause severe efficiency problems, and there's no way to fix it once it's buried. It's better to have a loop that's slightly oversized. But if loop sizing is too generous, the installation gets expensive fast. Be sure that your installer has support from the heat pump manufacturer or plenty of local experience in loop sizing, and be sure the designer takes the local soil conditions into account.

Closed-loop systems typically vary from 100 to 150 feet of trench or bore hole per ton of heat-pump capacity, which accommodates 200 to 300 feet of pipe (assuming two pipes, one feed and one return). Be wary of any closed loop with less than 200 feet of pipe per ton. (One ton is 12,000 Btu/hour in heat or AC output.) Some configurations, like 4- or 6-pipe trenches, or "slinky" loops with extended spirals, use shorter trenches but much more pipe (Figure 5, next page).

Pipe diameter is critical to proper loop design, and must be calculated by a qualified designer. Substituting a smaller or larger pipe diameter can lead to poor performance (Figure 6, page 5).

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Figure 4. Each of the four bore holes for this vertical loop installation was grouted after the pipes were installed. The grout improves the thermal conductivity between the soil and the loop.

Connection method. Any underground connections must be heat-fused — never glued or mechanically fastened (Figure 7, next page). Pipe connections should be pressure-tested before backfilling.

Backfill material. Be sure loop trenches are backfilled with material that is free of sharp rocks that could cut the pipes.

Loop flushing. Loops must be flushed with a high-powered water pump to clean out air bubbles and any contaminants. If the flushing pump is too small, it will be unable to remove all the air bubbles, especially in a slinky installation.

Open-Loop Systems

Open-loop installations take water directly from a well or other source. There are three types of open-loop systems: “pump and dump,” two-well, and standing-column.

In a pump-and-dump system, water is pumped out of a well, run through the heat pump, and then disposed of. This only works if there is an acceptable place to drain the water. Conservation authorities can be wary of pump-and-dump systems, but I’ve seen outflows dumped acceptably into ponds, streams, drywells, and even into a municipal sewer system. Just be sure to ask first, before you get into trouble.

Two-well systems pump water from one well through the heat pump, then back into another nearby well. There are standards for the minimum distance between the wells. These systems are less common than single-well systems, because the extra drilling can be expensive.

Standing-column systems use a single well, often the same well used for the domestic water supply. The water for the heat pump is pumped out near the bottom of the well, and returned back near the top of the well, but below the surface of the water. As a rule of thumb, a standing-column system requires a minimum of 60 feet of vertical separation per ton of heat pump capacity between the submersible pump and the return discharge.

Although a standing-column system uses 3 gallons per minute of well water per ton of heat pump capacity, the actual flow or yield from the well can be less, because all or most of the water is pumped back into the well. It helps if the static water level (the top of the water column) is relatively close to the surface — ideally, within 30 feet of grade. Lower static water levels require more power to pump the water through the system, and therefore result in less efficient performance.

Carefully consider the following issues before putting in an open-loop system:

Pump sizing. I have tested many open-loop systems that cost the owners 50% to 100% more to run than

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Figure 5. This closed-loop system uses “slinky” coils, installed horizontally in a wide excavation. The ground loop is being backfilled with clean material.

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Figure 6. This polyethylene pipe has been prepared for lowering into a bore hole for a vertical ground loop. The U-fitting will sit in the bottom of the bore hole.

expected because of oversized well pumps. The big, 240-volt beasts used to pressurize domestic water systems use two to four times as much power as a small circulator, which is all that's needed to move fluid in a closed loop. The pump size should be carefully engineered; don't let a well driller talk you into a larger pump, just to be "safe."

Flow rate. Flow rate through the heat pump is usually controlled by a ball valve or a flow regulator. If the flow is too high, it can damage the heat exchanger and will also cost more to run. However, low flows can reduce output. Heat pumps with two-speed compressors are designed to run on low speed where there isn't much demand for heating or cooling, to save power. These systems need separate flow control for low speed; if the water flow isn't matched to the lower speed, it may cost even more to operate at low speed than at high speed.

Operating pressure. It can be tricky to design an open-loop system that shares a well with domestic water, because the domestic water system needs a higher water pressure than the heat pump, which needs only 15-20 psi to operate. Don't give in to the temptation to oversize the submersible pump just to satisfy the need for high pressure for the domestic water supply. A better solution is to add a second pump (an indoor jet pump) and a separate pressure tank just for the domestic supply.

Bleed water dumping. Standing-column wells may need a bleed control that senses the incoming water temperature. This control diverts a small amount of the flow away from the return pipe when the well gets too cold. As with a pump-and-dump system, you need an acceptable place to dispose of this water; but since the amount of water is less (only about 10% of the flow through the machine), it's much easier to deal with.

MIKE GUERTIN

Figure 7. Heat-fusion joining is used to make joints in the polyethylene pipe of a closed-loop ground-source heat pump. When properly made, such joints are said to be stronger than the pipe itself.

Installation Requirements

Regardless of loop type, every geothermal installation requires a tightly-built house, well-installed ductwork, and coordination between the various subcontractors.

Build a tight shell. Never put a geothermal system into a home that isn't well insulated and tight. Because of the high initial cost of geothermal equipment, it's almost always cheaper to upgrade the building envelope with extra insulation, better windows, and air-sealing work than it is to install a larger heat pump. Explain the energy details of the building to the hvac contractor, so he can perform accurate heating and cooling load calculations.

Insist on high-quality ductwork. Heat pumps are not sized to provide the excess capacity that would be necessary to make up for undersized or leaky ductwork (Figure 8, next page). I've seen poorly installed ductwork that puts more heating or cooling air into the attic or garage than to some rooms. Be sure your installer seals all duct connections with mastic, not duct tape, and insulates the ducts thoroughly (Figure 9, next page).

Plan ahead: Work with the hvac contractor to allow space for the ductwork in the building design. If possible, keep ducts out of the attic. If ducts must be installed in an attic, be sure they are well sealed and run low to the ceiling. Then cover the ductwork with loose-fill insulation to achieve a higher R-value than you would get with typical duct wrap.

Make communication between subcontractors a high priority. In some

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Figure 8. This branch duct jumps under a beam and across a joist bay, creating friction losses and reducing air flow. Plan the location of duct runs before framing begins, to avoid complicated ducts like this one.

heat pump installations, up to four different subcontractors are involved (the excavator, the well driller, the electrician, and the hvac contractor). With this many subs, there are plenty of opportunities for miscommunication.

Design & Testing

You may be wondering, "Do I need to be a heat-pump expert to put one in a house I'm building?" No, you don't need to be an expert — but you should know enough to ask a potential hvac sub the right questions:

Are you planning to do a complete heating and cooling load calculation? The Air Conditioning Contractors of America (ACCA) *Manual J — Residential Load Calculation* is the industry standard. Several software programs are available to help speed up load calculations. Good practice requires the contractor to measure wall, ceiling, floor, and window areas; to include insulation levels and window performance data; and to look at the house's compass orientation, since this affects cooling loads dramatically. Verify that the subcontractor is performing calculations for each room, not the whole building. With gas or oil heat, you can be sloppy in estimating heating requirements, because a larger furnace costs only a few hundred dollars more. But with a heat pump, one size too big can cost thousands. On the other hand, if your installer undersizes the unit, the house may require so much electric resistance heat to make up the difference that your customer will end up with an outrageous electric bill.

What about the duct design? Your hvac sub should base the duct design on ACCA's *Manual D — Residential Duct Systems*. Avoid flex duct, which is easily punctured and tends to develop sags and kinks.

How about factory support? Make sure the manufacturer of the equipment has a rep who offers good support, and that your hvac sub isn't afraid to use it. If possible, find a contractor who has attended a factory-authorized training program on geothermal installations.

What type of startup testing do you perform? When the system is in place, your contractor should do more than plug it in and see if it works. The minimum required tests include: water flow rate, temperature change across the water coil, temperature across the air stream, and the air pressures ("static pressures") in the main supply and return ducts. Such tests only take a few minutes. If all these values aren't within factory limits, something is probably wrong — and if so, *all* of the tests will need to be repeated after the problem is fixed.

Never use a contractor who doesn't have a substantial amount of experience with geothermal systems. You can look at a previous job to see if he thoroughly sealed the duct connections with mastic, used smooth, rounded fittings and direct duct runs rather than long, twisted runs with many abrupt transitions, and minimized use of flex duct.

Any installer with a good track record should be able to supply the names of several happy customers who will tell you that their house is comfortable and their electric bills are low. If you can find the right sub, you should be well on your way to providing a comfortable, efficient, and trouble-free geothermal system for your customers.

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MATTHEW ORIO

Figure 9. The ductwork for this heat-pump installation has been carefully insulated.