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Pull money from the ground with geothermal heat pumps

Geothermal (or ground-source) heat pumps forego the cooling tower/boiler combination and instead use water circulated to and from the earth to provide heat exchange, which results in a more environment-friendly system.

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By Robert J. Flaherty, P.E.

Heat pump technology has been used in residential and commercial buildings for decades. Typical water-source heat pump systems circulate water through cooling towers or boilers to provide a constant-temperature heat source or heat sink for their operation. Geothermal (or ground-source) heat pumps forego the cooling tower/boiler combination and instead use water circulated to and from the earth to provide heat exchange, which results in a more environment-friendly system.

Heat pump operation

Heat pumps operate on a thermodynamic cycle known as vapor-compression refrigeration. In the cooling mode, the heat pump functions as an air conditioner, wherein heat is removed from a space. In the heating mode, refrigerant flow reverses and adds heat to the conditioned space.

The vapor-compression cycle consists of four basic components. The compressor provides energy to circulate the vapor phase refrigerant and to raise its pressure and temperature so it can condense to a high-temperature, and high-pressure liquid as it flows through the second component, the condenser. The condenser is a heat exchanger (a coil) through which high-temperature refrigerant flows and transfers its heat to the heat sink. In a water-source system, the heat sink is the circulating water mentioned above.

The liquid refrigerant flowing from the condenser passes through an expansion device generally known as the thermostatic expansion valve (TXV). The TXV meters the refrigerant flow to match the load and throttles the flow, which reduces the liquid refrigerant's temperature and pressure while holding its energy content -- its enthalpy -- constant. This phenomenon is known as the Joule-Thompson Effect.

The low-temperature, low-pressure liquid then moves to another heat exchange coil, the evaporator. Here, the liquid refrigerant absorbs heat from the source, which is really the medium to be cooled, the load. As the source cools, it heats the refrigerant enough to cause it to evaporate within the coil, transforming it back to a low-pressure, low-temperature vapor that returns to the compressor to repeat the cycle.

A heat pump includes a fifth component that allows refrigerant to flow in the opposite direction, thereby allowing the condenser to function as an evaporator and the evaporator as a condenser. Avoid confusion when discussing heat pumps by replacing the terms evaporator and condenser with indoor coil (the coil that transfers energy between the refrigerant and the conditioned space) and outdoor coil (the coil that transfers energy between the refrigerant and the environment). Figures 1 and 2 show the refrigerant flow diagram in both operational modes.

Fig. 1 BTUs outward



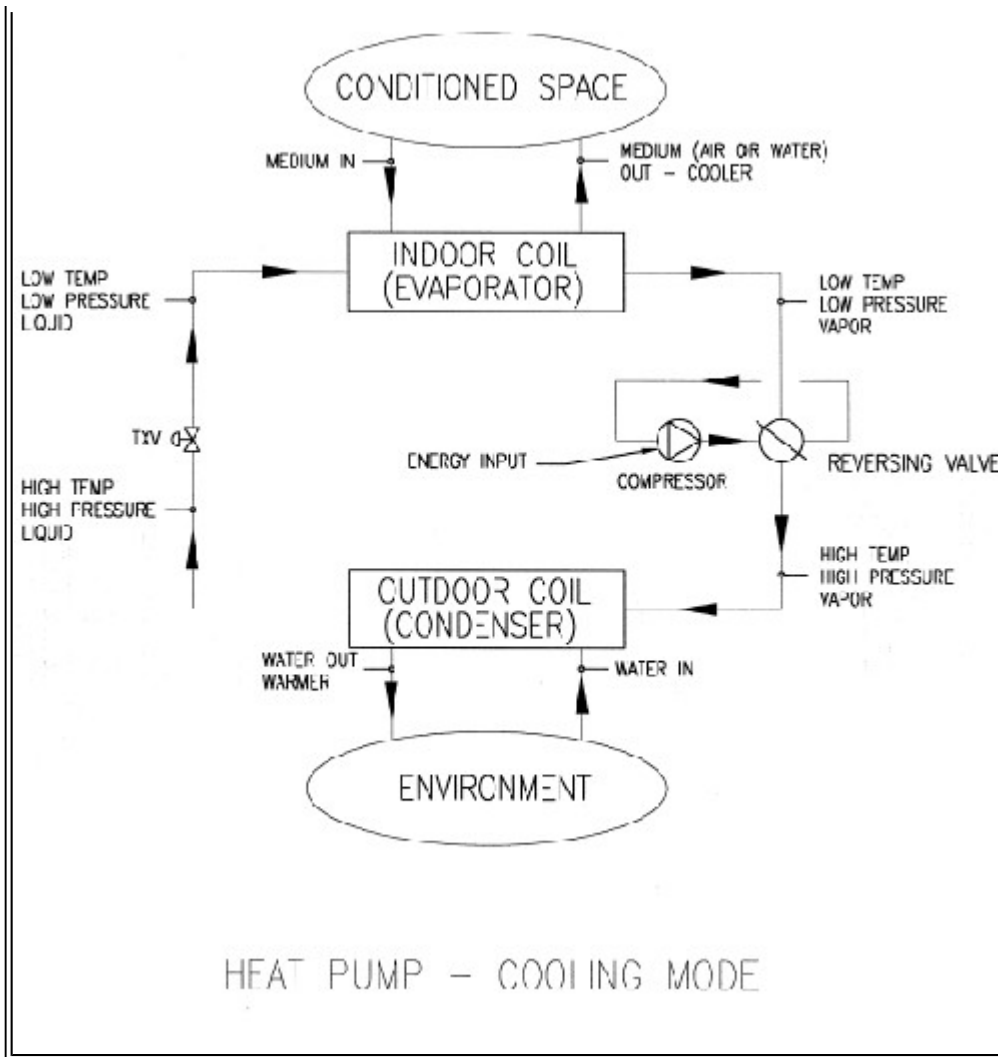
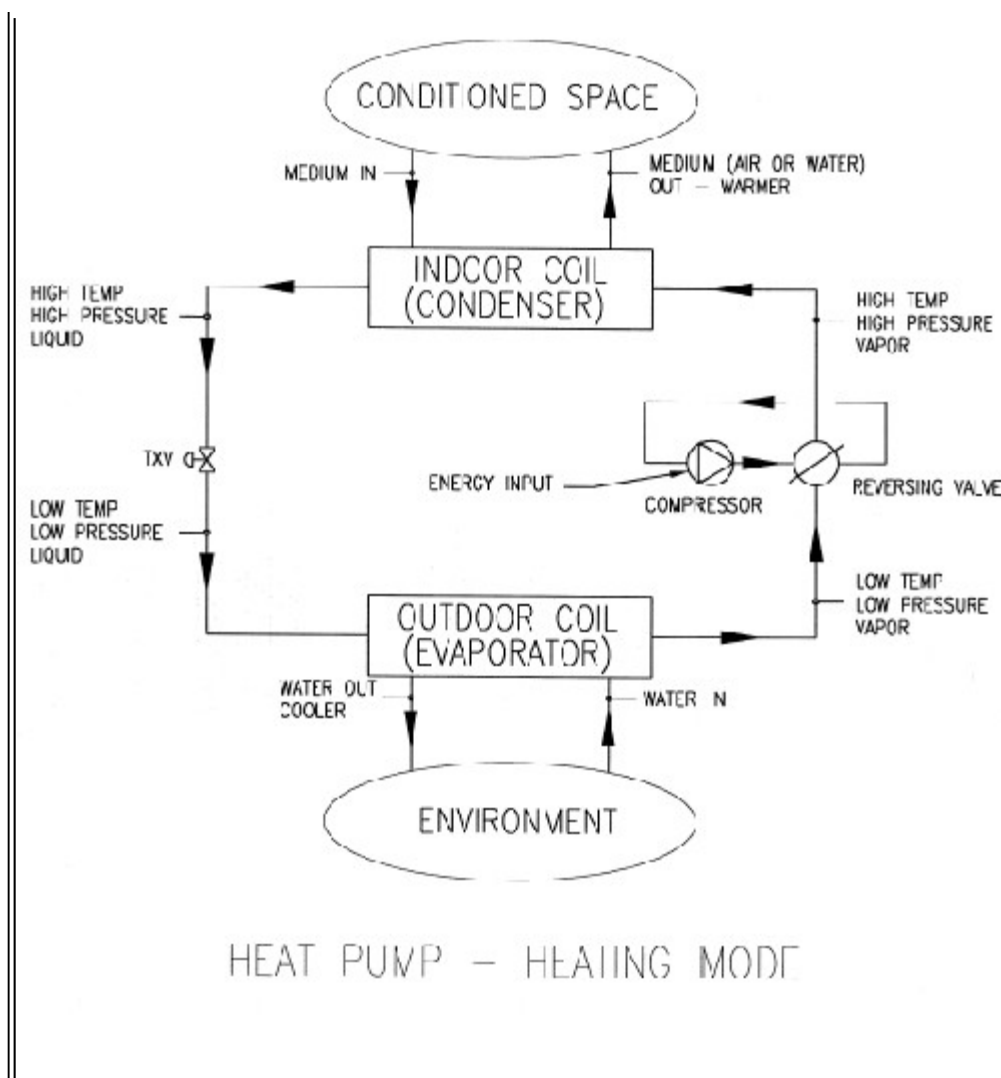


Fig. 2 BTUs inward





Geothermal heat exchange

The heat pump either absorbs heat from or rejects heat to the environment through intermediate devices such as boilers or cooling towers or directly through geothermal exchange.

Many sources of geothermal energy aren't readily available or have environmental concerns. An available source (to some) might be a lake, pond, river or ocean. Not every site has access to a body of water, and changing the thermal equilibrium in these bodies has the potential to affect the local ecosystem.

Two generally available subsets of geothermal exchange are the ground-coupled heat pump (GCHP) and ground-water heat pump (GWHP). Both systems exchange energy with the earth and have the advantage of being contained entirely within the plant's boundaries.

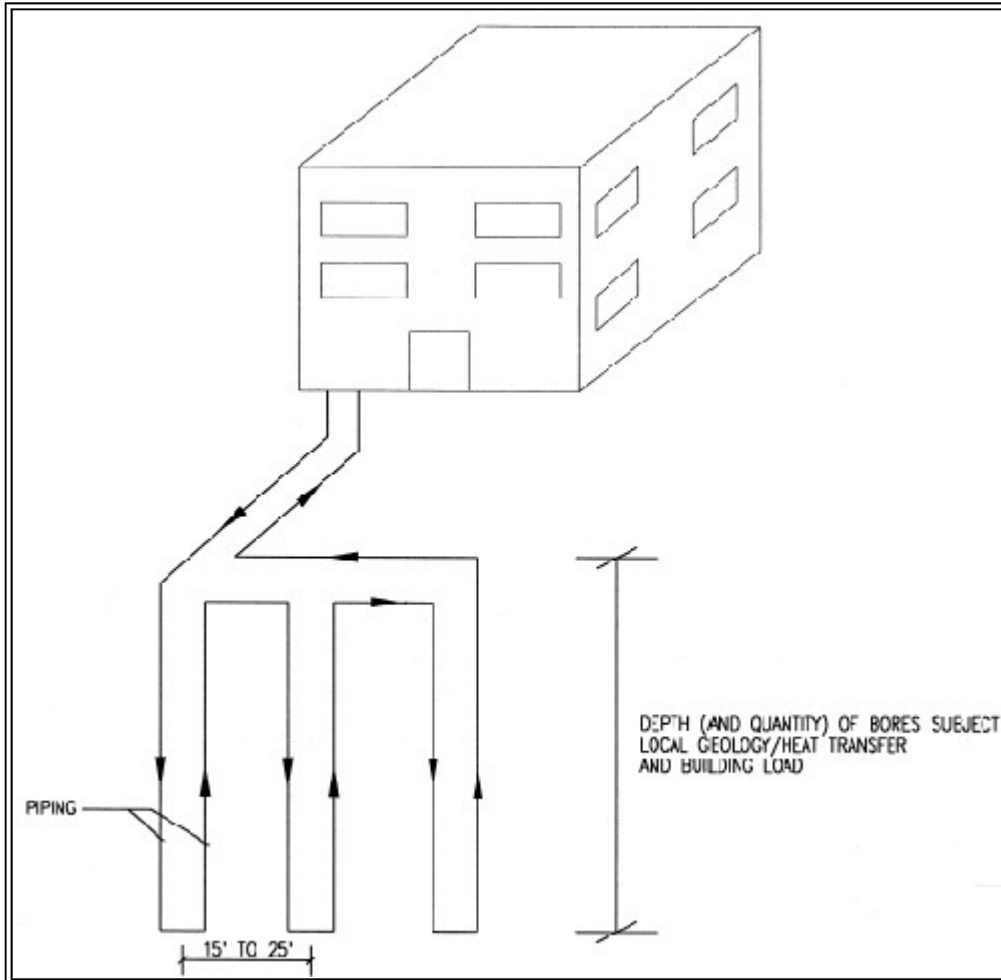
In a GCHP system, heat is transferred to and from the ground through a sub-surface network of piping, which acts as a heat exchanger. The goal is to make the temperature of the water circulating within those pipes approach the relatively stable temperature of the soil at depth. In heating-dominated regions, the working fluid is an antifreeze solution because portions of the piping network could be within the frost zone.

Ground-coupled heat pumps

GCHP systems are further classified as vertical or horizontal designs. As the name implies, the vertical GCHP circulates water or antifreeze solution through a series of deeply buried pipes (Figure 3). Designing a vertical system requires a geotechnical consultant or geologist to determine the site's geology where the pipework will be installed. Given that input, the thermal

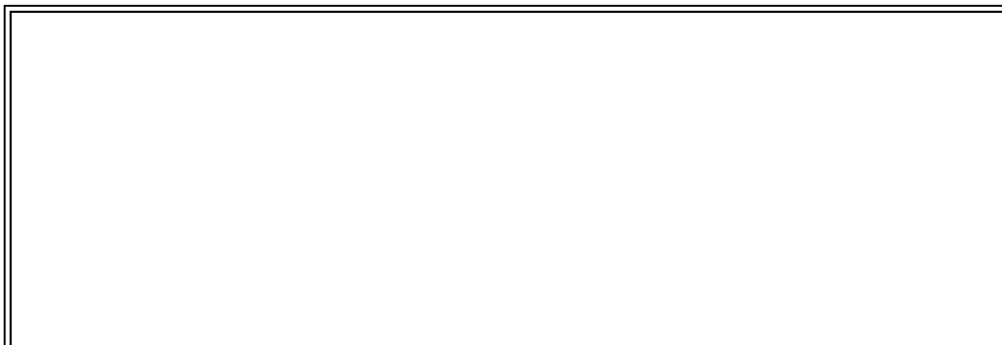
performance of the rock and soil formations can be estimated to determine the overall underground heat transfer rate. This information, in turn, determines the quantity of vertical pipes (and bores) needed to transfer the energy required to meet the building's needs. Most installations require multiple bores spaced 15 to 25 ft. apart. The exact number depends on the equivalent full-load hours (EFLH) the system will operate (in heating and cooling) and on the building load.

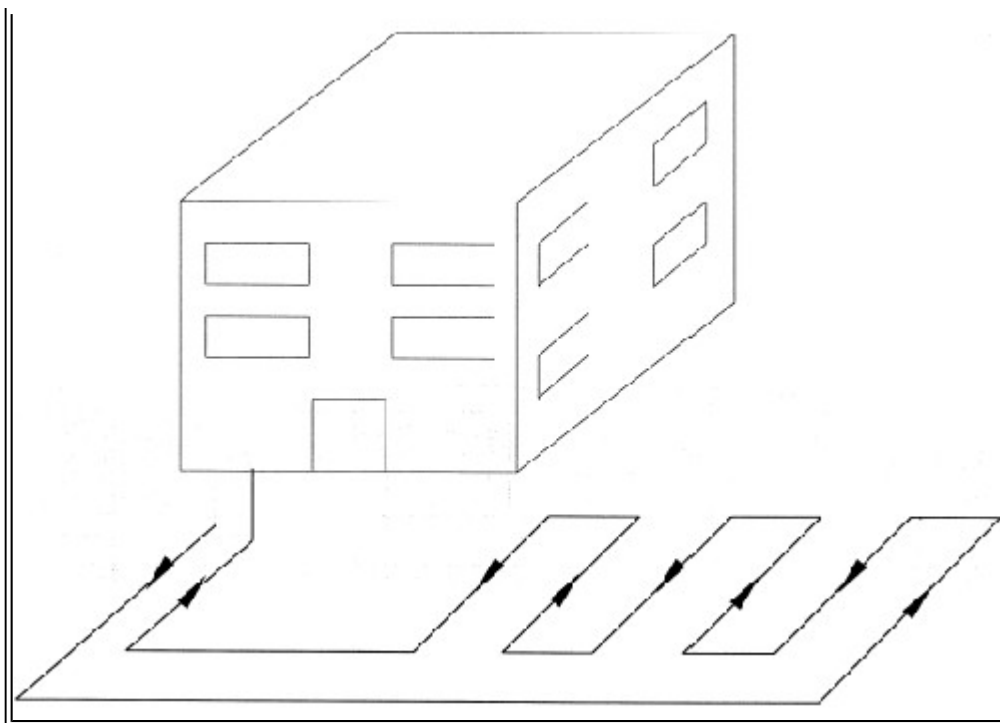
Fig. 3 The deep way



Horizontal GCHP systems use a network of pipes or coils distributed horizontally, at shallow depth, around a site (Figure 4). Similar to the vertical system, the pipes and coils act as heat exchangers that exchange energy with the ground. The geology close to the surface is generally known, and designing a horizontal system doesn't involve the same potential pitfalls as a vertical system.

Fig. 4 In one, out the other





The obvious critical variable with the horizontal GCHP is adequate space on the property to spread out the underground lines. To minimize space requirements, multiple pipes can be placed in a single trench. An alternative method includes spiraling the pipe into a coil. Both approaches require careful backfilling to ensure the pipework is in full contact with the soil. Another consideration is that multiple pipes in a single trench won't increase the energy exchange rate proportionally. Two pipes in one trench are less than twice as effective as one pipe in a trench. The reason is thermal interference between pipes.

Assuming adequate space is available for the required energy transfer, the horizontal system offers several advantages over the vertical system. These include:

- Known geology, therefore, more confidence in the heat exchange rate.
- Lower excavation cost, as the site is likely to be partially excavated as part of the normal construction process.
- Lower installation cost (backhoes for trenches versus drilling machines for bores).

But the horizontal system has its disadvantages as well:

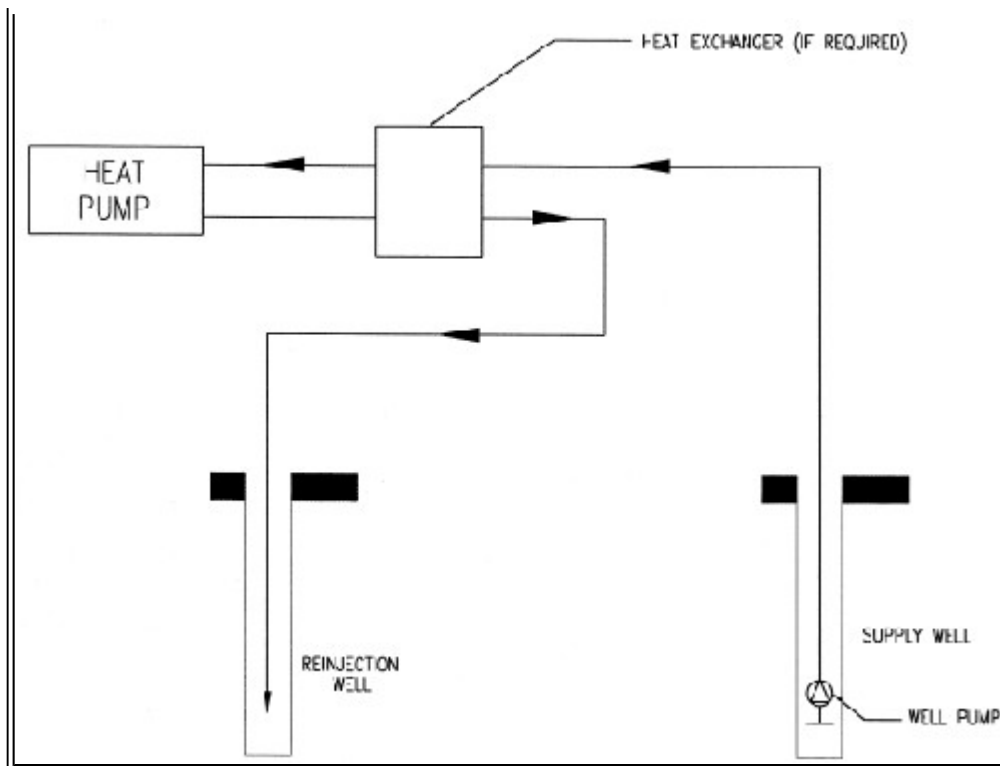
- Pipe loops close to the surface are subject to damage during future earthwork projects.
- Rocks or a ledge may need to be removed.
- Additional excavation beyond normal construction is likely.

Ground water heat pumps

GWHPs use ground water from a well system, either directly or through an intermediate heat exchanger, to transfer energy between the outdoor coil and the earth. The components of a GWHP system (Figure 5) include a supply well and pump, a heat exchanger (if necessary) and an injection well (if necessary).

Fig. 5 A real closed loop





The supply well should produce 2 to 3 gpm per ton of refrigeration (1 ton = 12,000 BTU/hr.). This generally requires fairly deep wells, something on the order of 1,500 ft., to ensure a stable water temperature while providing an environment for heat exchange similar to a vertical GCHP. It's possible, in some areas, to avoid the expense of an injection well by returning the water back to the supply well.

In certain climates, the heat exchange rate in the 1,500 ft. bore is inadequate to bring the return water temperature close to the supply water temperature. Additional controls might be necessary to divert water returning to the well to avoid influencing the ground water temperature. The diverted well water will go to the storm or sanitary sewer system. This might require an understanding and approval from the local authorities having jurisdiction (water and sewer commission, water resources authority) and might not be an available option in every jurisdiction.

Design considerations

Of the systems discussed (vertical GCHP, horizontal GCHP and GWHP), the ground water option provides the largest capacity. A typical 1,500 ft. well can provide adequate flow to accommodate about 420,000 BTU/hr. of both heating and cooling. Depending on the site, multiple wells could be drilled to multiply this capacity. On the other hand, a network of pipes and coils installed for a GCHP is limited to a practical capacity of about 120,000 BTU/hr. Space constraints and cost concerns make multiplying the network of pipes impractical.

Any of the systems could be applied to a distributed network of smaller heat pumps (a unitary system), each of which is sized for the load in an individual space. The diversified total load designed must not exceed the capacity of the geothermal exchange of energy. These unitary heat pumps (1 to 3 tons capacity) typically use air as the medium on the outdoor coil (water-to-air heat pumps).

Additionally, the GCHP or GWHP could be arranged in a central plant configuration, limited only by the capacity of the geothermal exchange. In this case, the heat pump would be of larger capacity (as much as 35 tons) and located in a mechanical room. The medium on the indoor coil would be water (water-to-water heat pump), which would then be circulated throughout the building to heat or cool it.

Further considerations

These geothermal systems involve costs above those associated with a typical cooling tower/boiler source system. However, operational and maintenance costs can prove to be lower, especially in areas with high fuel, water and sewer rates. Additionally, because geothermal heat pumps use less electricity than comparable systems (no cooling tower fans or basin heaters) there may be utility rebates available to offset some of the costs. Most of the higher cost has to do with site development, whether boring for wells or vertical pipework, or excavating trenches for horizontal pipes and coils.

In many areas, potable water is a scarce resource, but site wells are drilled for nonpotable use such as irrigation. It's possible to use these wells in a GWHP system if appropriate controls disable the irrigation during peak heat pump demand. In this way, the well for the heat pump is installed for free.

In any event, as with any mechanical system, you should perform a detailed life-cycle cost analysis to determine the best solution for your building. Don't forget the intangibles associated with geothermal exchange.

Environment-friendly: It loses no water to evaporation as with a cooling tower. It has no need for the chemicals associated with cooling towers. It burns no fossil fuel.

Space-saving: It requires no condenser water pumps for the cooling tower (well pump is outside). It avoids having to store cooling tower chemicals. It has no boiler combustion air system.

Aesthetics: It uses no outdoor equipment (cooling towers must be outdoors) or boiler flue or chimney. It produces no outdoor noise.

Some of these intangibles can be quantified and have dollars associated with them, while others can't, but that doesn't mean they're without value.

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