Small Scale Geothermal

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Table of Contents

- Introduction to Small Scal
- How Do They Work?
- Example Problem
- Helpful Websites

Introduction to Small Scale Geothermal

Using geothermal heat pumps to heat and cool a home can be a great way to save money by reducing energy bills. This is because typical HVAC systems must add a lot of heat to a home’s air when it is very cold outside to keep the temperature indoors warm. Typical HVAC systems must also remove a lot of heat when the outside air is very warm to keep the home cool. When HVAC systems operate, they depend on the outside air to add or remove heat. The outside temperature also effects how efficient the system operates. Geothermal systems use water that is pumped through piping system below the frost line underground where the temperature is the same all year. This allows the system to operate at the same efficiency all year long. The average temperature of the lower 48 states is about 60°F and in Iowa the average temperature is 53°F at a depth of 36 inches. By using the ground temperature, the heating/cooling system does not add or remove as much heat to the air, increasing the efficiencies of heating and cooling a home. Using a geothermal system could cut energy bills by 25% to 50%.

During the summer months, to keep the home cool heat is extracted from the home and the heat is transferred to the water running underground. The ground absorbs this heat and returns cool water to the home. During the winter months, the flow is reversed and the heat in the ground is captured by the water running underground and is used to heat the home. Using this cycle allows the system to use less natural gas or electricity, depending on what type of HVAC system is used by the home. The following equations are used in determining the coefficient of performance, COP, of a system:

\[ \text{COP} = \frac{Q_{out}}{W} \]

The higher the COP, the more efficient a system is working. For a hot summer day when the temperature outside is 90°F and inside temperature is kept at 70°F. The COP is about 26.5 for a traditional HVAC system. For a cold winter day when the outside temperature is 20°F, the COP drops to 10.6. The colder the day the worse the COP is. For a geothermal system, the COP is the same for winter and summer months because the outside temperature has no effect on the COP. Instead the ground temperature, which remains constant, allows the COP for a geothermal system to be about 53 all year long. This means that the system works more efficiently, thus, saves energy and money.

**Figure 1**: This is a schematic of a typical geothermal system in cooling mode. For the heating mode, the arrows showing the fluid movement would be reversed and latent heat would be exchanged with the refrigerant.
For people who do not want to learn to operate a new technology, operating a geothermal system is the same as operating a typical central air system with a similar thermostat. The operation of the heat pump also works much like that of a typical HVAC system, which uses refrigerant in a compression /evaporation cycle.

Figure 2: Cooling and heating mode with a geothermal water heater integrated.
How do they work?

Different Types of Geothermal Systems

The geothermal system consists of two heat exchanging loops. The primary loop is a refrigerant filled loop that exchanges heat with a secondary loop. The secondary loop can be of two types and can be arranged in two types of arrays. The two types of geothermal arrays are vertical and horizontal. Vertical loop systems have the heat exchanging pipe that run in vertical wells.

**Figure 3:** A vertical closed loop geothermal system

Horizontal loop systems run the pipes in a horizontal array.

**Figure 4:** A horizontal closed loop geothermal system

Either the vertical and horizontal loops can have the coils in a “slinky” setup as well. This reduces the length of the overall loop by overlapping the coils.

**Figure 5:** A horizontal “slinky” type closed loop geothermal system
The vertical and horizontal systems can either be open or closed loop. Most systems in use are closed loop which a refrigerant loop exchanges heat with an underground loop that uses a water/antifreeze mixture. An open loop systems replaces the underground closed loop water/antifreeze loop with an open loop that uses water from an underground or surface source such as a lake (surface source) or a well (underground source).

**Figure 6:** Open loop system in comparison to a closed loop system

Open loop systems are much more efficient than closed loop systems. Open loop systems are subject to salt, minerals, and bacteria’s so it may not be available to use in all areas. Bad water conditions may subject the system to corrosion, scaling, and bacteria that may damage the system or reduce the service life. The water conditions may change over time and installing an open loop system today might become a waste of resources if next year the water quality has dropped to the point that it could cause damage to the system. The water source must be able to supply about 3 gallons of water per minute per ton of heat pump capacity. The water source should not be subject to flooding as this could damage the loop. Another issue is that in some areas, open loop systems have been outlawed because of concerns that groundwater systems can be depleted or damaged.

Closed loop systems may not be as efficient as open loop systems, but they don’t require periodic cleaning. A closed loop system’s efficiency can also be improved by laying soaker pipes near the heat exchanging loop to increase the rate of heat transfer. Since closed loop systems are less efficient, more pipes are needed to release or extract the required amount of energy from the ground.

**Figure 7:** A "slinky" type pond geothermal system
The type of soil may also be a factor when deciding to install a geothermal system. Poor soil will result in the need of using more pipes for the loop.

Construction and Integration

When deciding whether to use a geothermal system for your home a question that you may be asking is “How can it be integrated in to my existing home”? A geothermal system consists of a heat pump, ground coils, the duct work, and the thermostat. If the home already has a forced air system, the duct work doesn’t need to be changed. The heat pump would replace the existing heater and air conditioning components. For an existing home, the only major work that would need to be done is the ground coils. This can be an issue if the homeowner wants a horizontal coil setup as this setup requires a large amount of space. If the plot of land that the home sits on is not large enough to allow for the horizontal coils, one of two options may be viable. Using a vertical loop system is probably the likely choice. The other option is to use the “slinky” approach, reducing the length of the trench. If the home has yet to be built, the construction and integration of the system into the home is the same as installing and integrating a typical HVAC system but with exterior work needing to be completed.

Economics of Geothermal Systems in Homes

To estimate the size of geothermal unit that will be needed, it can be assumed that a one ton unit can generate 12,000 Btu. For a typical home of 2000 square feet requiring about 36,000 Btu in the winter, a three ton geothermal unit would be needed. The cost of a geothermal unit runs about $2500 per ton of the unit, so a three ton unit would cost approximately $7500. Other costs of installing a geothermal system come from digging the trench or drilling wells for the ground loop, compacting the soil after the ground loop has been installed, landscaping the land, and any updates to an existing home. These updates might include the addition of duct work if the existing home does not have a forced air system installed. Geothermal could also be used in the water heating system, allowing the water heater to be more efficient. Although the cost of adding a geothermal unit to a home may have a large upfront cost, the payback period could be relatively quick depending on the homes insulation.

Advantages and Disadvantages of Geothermal
For people who desire to become eco-friendly, the reasons for switching to a geothermal system are clear, less wasted energy and a lower carbon footprint. Another advantage can come in the form of money. Many utility companies, as well as, the federal government, provide incentives for installing systems like geothermal heat pumps. In the Iowa City area, MidAmerican Energy offers up to $2000 for a ground source heat pump, $400 for heat pumps, and $100 for heat pump water heaters. To see what your utility company offers see the DSIRE (Database of State Incentives for Renewables and Efficiency) website at www.dsireusa.org.

Geothermal systems can be installed into existing homes. This requires substantial outside work installing the ground loop. The size of the yard may prohibit the use of a desired loop setup. Newer homes with excellent insulation may not have as much as an advantage of using geothermal heat pump system since the payback period is almost as long as typical life expectancy of the system, whereas, a existing home with poor insulation may see a payback period of 10 years.

**Example Problem**

Dubuque, IA
Type of home: Single family, one story
Unique features: Radiant floor heat, styrofoam concrete construction and heated garage
Living space: 1,934 square feet, plus 936 sq. ft. garage
Winter design heat loss: 39,834 Btu/hour house, 22,308 Btu/hour garage
Summer design heat gain: 18,612 Btu/hour house, 8,628 Btu/hour garage
Installation: Three ton WaterFurnace
Horizontal loop: 2,500 feet of polyethylene pipe
Heating season: $366.57 (8,451 kWh)
Cooling season: $160.91 (2,923 kWh)

The above data is of an existing home with a geothermal system installed. This data was found on http://www.alliantenergygeothermal.com/GeothermalInAction/Residential/000369 and was used as a comparison for the solution to the equations below.

**Assumption used:**
\[ C_p = 1 \text{ Btu/lb}^\circ\text{F} \]

**Equations used:**

Effectiveness of a heat exchanger:

- \( A \)
- \( B \)
- \( C \)
- \( D \)
- \( E \)
- \( F \)
- \( G \)
- \( H \)
- \( I \)
- \( J \)
- \( K \)
- \( L \)
- \( M \)
- \( N \)
- \( O \)
- \( P \)
- \( Q \)
- \( R \)
- \( S \)
- \( T \)
- \( U \)
- \( V \)
- \( W \)
- \( X \)
- \( Y \)
- \( Z \)

Thermal conductivity of the pipe:

- \( a \)
- \( b \)
- \( c \)
- \( d \)
- \( e \)
- \( f \)
- \( g \)
- \( h \)
- \( i \)
- \( j \)
- \( k \)
- \( l \)
- \( m \)
- \( n \)
- \( o \)
- \( p \)
- \( q \)
- \( r \)
- \( s \)
- \( t \)
- \( u \)
- \( v \)
- \( w \)
- \( x \)
- \( y \)
- \( z \)
Thermal conductivity of soil:

Unknown macro: 'mathinline'

Thermal conductivity of water:

Unknown macro: 'mathinline'

Overall conductance of the heat exchanger:

Unknown macro: 'mathinline'

Mass flow rate inside the pipe:

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Unknown macro: 'mathinline'

Reynolds number inside the pipe:

Unknown macro: 'mathinline'

Relative roughness inside the pipe (for use with the Moody diagram):

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Heat transfer correlation for internal pipe flow with fully developed flow:

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Heat transfer coefficient in the pipe:

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Length of pipe needed to obtain the desired heat exchange:

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Typically, the Moody Diagram below is used to find values of some of the equation variables above. For the example problem, [http://www.mcquay.com/mcquaybiz/literature/lit_systems/AppGuide/AG_31-008_Geothermal_021607b.pdf](http://www.mcquay.com/mcquaybiz/literature/lit_systems/AppGuide/AG_31-008_Geothermal_021607b.pdf) was used because it provides many of the needed variable values, beginning on page 36, with our values of 3 gal per min flow rate and 1.25 inch pipe. This article is an excellent source for an indepth look at geothermal systems.

![Moody Diagram](image)

**Figure 8: The Moody Diagram**

CO2 production in a home using natural gas heater with an electric air conditioner to a home with a geothermal system, the following equations were used:

**Home without geothermal:**

**Heating:**

Amount of CO2 released from burning natural gas in a high efficiency furnace to heat a home.

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**Cooling:**

Amount of CO2 released using coal produced electricity to cool the home.

□ Unknown macro: 'mathinline'

**Home with geothermal:**

**Heating:**

Amount of CO2 released using coal produced electricity to run a geothermal unit for heating.

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**Cooling:**

Amount of CO2 released using coal produced electricity to run a geothermal unit for cooling.

Heating values used in these equations were found using the following website:
http://climatemaster-residential.clickforward.com/svcalc

Values for lbs CO2 per kWh of coal produced electricity:


Value for lbs CO2 per billion Btu of natural gas:
+http://www.naturalgas.org/environment/naturalgas.asp+

This example shows that when comparing the two homes, the CO2 production is about the same when using natural gas/electric non-geothermal home and a geothermal home with electric heating and air conditioning. This is using electricity produced by a coal fired power plant. If a renewable energy source was to be used, the CO2 emissions would be greatly reduced.

**Interesting Sites**

http://www.duanesworld.net/duanesworld.net.geothermal.htm
http://www.ourcoolhouse.com/
http://climatemaster-residential.clickforward.com/svcalc

**Installation guides and more information**

http://www.energybible.com/geoenthal_energy/
http://www.alliantenergygeothermal.com/WorkingWithIt/Designing/000284
www.dsireusa.org