



**GEOHERMAL 101:  
THE BASICS AND APPLICATIONS OF  
GEOHERMAL ENERGY**

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12 SEPTEMBER 2011

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## Geothermal 101

### *The Basics and Applications of Geothermal Energy*

#### Introduction

The average household in the United States uses 56 percent of its energy consumption for heating and cooling, accounting for the single largest energy expense for homeowners<sup>1</sup>. Also, buildings in the US are responsible for a large share of the nation's energy consumption and carbon dioxide (CO<sub>2</sub>) emissions, representing 39 percent of total energy consumption and 43 percent of carbon emissions.<sup>2</sup>

With growing concern over rising energy costs and the environmental impacts of supplying our energy needs, there is a great need to find economical and environmentally sound energy alternatives. However, amidst the push to expand renewable energies, one option that is rarely discussed is geothermal energy. One reason that geothermal is often overlooked is because of the lack of understanding how the technology works and a view that it is new and unproven. Actually, people have used geothermal energy for over 10,000 years with the first recorded use when Paleo-Indians settled around hot springs and used them as a source for warmth, cleansing, and healing.<sup>3</sup> More advanced geothermal technology, such as geothermal heat pumps, have been used to heat and cool buildings since the late 1940s and today more than 50,000 units are installed in the United States every year<sup>4</sup>.



Image 1: Hot Springs in Steamboat Springs, Nevada.

Source: U.S. Department of Energy.  
[http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)

While there are many ways in which geothermal energy can be applied, the focus of this paper is on residential applications of geothermal through the use of geothermal heat pumps (GHPs). Geothermal energy has significant potential as part of a renewable energy mix. Geothermal energy can be clean and reliable, and it is locally available in many areas.<sup>5</sup> The purpose of this report is to provide an overview of the basics of geothermal energy: how it works, how it can be used, and the advantages and disadvantages of the technology.

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<sup>1</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12300](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12300)

<sup>2</sup> Ellis, Daniel. "Geothermal Heat Pumps: Harnessing On-Site Renewable Energy to Meet Energy-Efficiency and Climate Change Goals." GeoExchange.org

<sup>3</sup> <http://www1.eere.energy.gov/geothermal/history.html>

<sup>4</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm?mytopic=12640](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm?mytopic=12640)

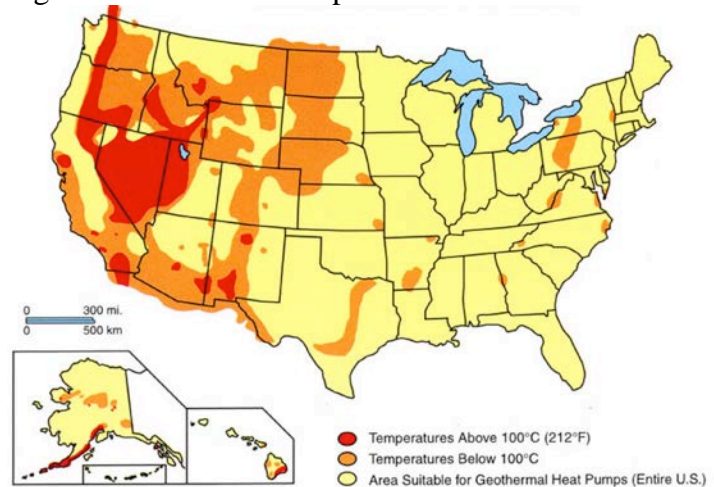
<sup>5</sup> [http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)

## Geothermal Basics

Geothermal is derived from the Greek words geo (Earth) and thermal (heat). The term “geothermal energy” refers to the harnessing of heat from underground sources ranging from the shallow subsurface, to reservoirs of hot steam, water, and rock deep beneath the Earth.<sup>6</sup>

Volcanoes, hot springs, and geysers, are all examples of concentrated geothermal energy that has made its way to the surface. In general, however, it is not obvious where pockets of concentrated geothermal energy are located because most sources occur unevenly and deep underground. To find and access a geothermal reservoir, water or steam wells are generally drilled to test temperatures.<sup>7</sup> Beyond concentrated geothermal pockets, there is some degree of geothermal potential almost everywhere because temperatures just several feet below the earth’s surface tend to remain a relatively constant 50 to 60 °F.

Figure 1. Geothermal Map of the United States



Source: Hulen, J.B. “Geothermal Energy.” University of Utah Energy and Geoscience Institute.

The map above (Figure 1) helps illustrate the uneven distribution of concentrated geothermal resources throughout the US. The highest heat flow levels and most geothermal projects are located in the western half of the US. Both in the US and globally, there is a large base of geothermal resources. Presently, much of this resource base cannot be tapped for use, but improvements in extraction technology of geothermal energy has significant potential to help meet a substantial share of future energy needs.<sup>8</sup>

Methods to utilize geothermal energy depend largely on local heat distributions. The factors that most influence the applications of geothermal energy are accessibility, water or steam temperatures, and geothermal reservoir permeability and porosity.<sup>9</sup> Applications can be broadly divided into three categories: power generation, direct heating, and ground source heating and cooling.

<sup>6</sup> [http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)

<sup>7</sup> [http://www.eia.gov/kids/energy.cfm?page=geothermal\\_home-basics](http://www.eia.gov/kids/energy.cfm?page=geothermal_home-basics)

<sup>8</sup> Hulen, J.B. et al. “Geothermal Energy.” University of Utah Energy and Geoscience Institute.

<sup>9</sup> Tester, Jefferson, et al. “The Future of Geothermal Technology.” Massachusetts Institute of Technology.

## Geothermal Applications

### *Geothermal Power Generation*

The United States currently generates more electricity from geothermal sources than any other country with 15 billion kilowatt-hours (0.4 percent of total US energy production) generated. As of 2009, California had thirty-five established geothermal power plants, Nevada had eighteen, and one each for Hawaii, Idaho, and Utah.<sup>10</sup>

Geothermal power generation requires heat flow temperatures ranging from 212 °F to 482 °F. Unlike intermittent power sources like solar and wind, geothermal energy is a reliable and consistent source of energy with an average system availability of 95 percent. Three categories of geothermal power generation are direct steam, flash, and binary plants.<sup>11</sup>

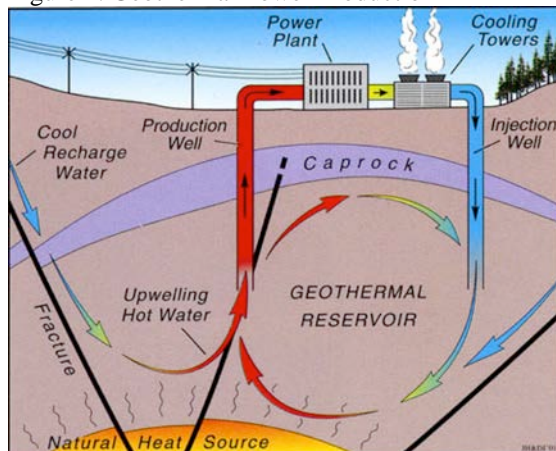
Direct steam plants require very high-temperature geothermal resources that are greater than 455 °F. These types of plants are both the rarest and most valuable because they have access to such high ground temperatures. The plants use high-temperature steam via production wells that are 3,280 feet to two and an half miles underground. The steam in these systems is processed so that particulates and non-essential fluids are removed and then it is piped to operate turbines that generate electricity.<sup>12</sup>



Image 2. Geothermal Power Plants at The Geysers, California.

Source: U.S. Department of Energy.  
[http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)

Figure 2. Geothermal Power Production



Source: U.S. Department of Energy.  
 Hulen, J.B. "Geothermal Energy."  
 University of Utah.

Flash-steam power plants are much more common and require resource temperatures ranging from 300-700 °F. These systems primarily use highly pressurized hot water that is transported to the surface via production wells reaching depths of two and a half miles underground. The pressure of this water is reduced during transport, a fraction of the water "flashes" or explosively boils into steam, and then this steam is moved to a turbine to generate electricity. Water that does not flash into steam is channeled back to the reservoir to maintain pressure and productivity.<sup>13</sup>

Binary-cycle power plants can utilize geothermal reservoirs ranging from 212 °F to 302 °F. Using these systems, hot water is circulated through a

<sup>10</sup> [http://www.eia.gov/kids/energy.cfm?page=geothermal\\_home-basics](http://www.eia.gov/kids/energy.cfm?page=geothermal_home-basics)

<sup>11</sup> "Energy Conversion." U.S. Department of Energy Office of Geothermal Technologies

<sup>12</sup> Hulen, J.B. et al. "Geothermal Energy." University of Utah Energy and Geoscience Institute.

<sup>13</sup> Hulen, J.B. et al. "Geothermal Energy." University of Utah Energy and Geoscience Institute.



heat exchanger which heats a secondary working fluid that turns to vapor at a lower temperature than water. Closed-loop systems use vapor to spin turbines to generate electricity. The vapor then condenses back into liquid and is transported back to the heat exchanger where the process begins again.<sup>14</sup>

### *Geothermal Direct-Heating*

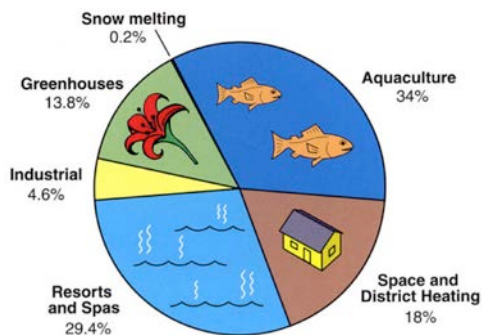
Even in areas with geothermal resources that are insufficient for power generation, such resources can still be used for direct-heating applications. Direct-heating use of geothermal energy involves utilizing low to moderate temperature resources (68 °F to 302 °F) to provide heat directly to a wide variety of residential, industrial, and commercial applications. Examples include homes, offices, commercial greenhouses, fish farms, food processing facilities, and mining operations as well as other direct-heating applications like melting snow on sidewalks. Geothermal direct-heating can produce cost savings up to 80 percent over conventional fossil fuels.<sup>15</sup>



Image 3: Snow melting on sidewalks in Klamath Falls, Oregon.

Source: U.S. Department of Energy.  
[http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)

Figure 3: Geothermal Direct-Heating Uses



Source: U.S. Department of Energy.  
 Hulen, J.B. "Geothermal Energy."  
 University of Utah.

Direct heating using geothermal energy is fairly widespread—especially in the Western United States—and is expanding. Presently, there are more than 40 greenhouse complexes, 30 aquaculture projects, and 220 geothermal resorts in the US that use geothermal space and district heating systems.<sup>16</sup>

The Department of Energy conducted a ten-state survey of geothermal resource potential in the western U.S. and identified over 9,000 thermal wells and springs, 900 low/moderate geothermal heat flows, and hundreds of potential direct heating sites to support potential direct heating applications. Approximately 270 of these sites were located near cities where there is the potential to displace fossil fuel use. The study estimated that 18 million barrels of oil could be displaced each year by using geothermal energy just for the heating of buildings in these areas.<sup>17</sup>

<sup>14</sup> Hulen, J.B. et al. "Geothermal Energy." [University of Utah Energy and Geoscience Institute.](http://www1.eere.energy.gov/geothermal/directuse.html)

<sup>15</sup> <http://www1.eere.energy.gov/geothermal/directuse.html>

<sup>16</sup> "Direct Use of Geothermal Energy." [U.S. Department of Energy Office of Geothermal Technologies.](http://www1.eere.energy.gov/geothermal/directuse.html)

<sup>17</sup> <http://www1.eere.energy.gov/geothermal/directuse.html>

### *Geothermal Ground Source Heating and Cooling*

Unfortunately, the potential for use of geothermal systems for power generation and direct use applications is less in the Eastern half of the US because of lower heat flow temperatures. Nevertheless, geothermal technologies can still be effectively used in some manner almost anywhere. The most viable means of accessing geothermal resources for states in the Eastern half of the US is via geothermal heat pumps (GHPs). A GHP<sup>18</sup> is an electric heat pump that transfers natural heating and cooling from the ground to regulate building air temperature.<sup>19</sup>

One of the largest advantages of GHPs is that just a few feet from the surface, ground temperature stays fairly constant (50 °F to 60 °F), whereas above surface temperature can vary significantly.<sup>20</sup> A relatively stable ground temperature means that GHPs can be installed almost anywhere in the US, achieving efficiencies of 300-600 percent during cold winters and hot summers.<sup>21</sup> These efficiency levels are many times greater than other heating systems. High efficiency traditional furnaces or boilers range between 90-97 percent annual fuel utilization efficiency.<sup>22</sup>

In the winter, a GHP works by utilizing the ground temperature that is warmer than the air above it to heat buildings; in the summer, the opposite process can be used to cool buildings where the heat from indoor air is transferred out of the house into the cooler ground. Basically, the ground can be thought of as a heat source during the cold of winter and a heat sink during hot summer months (Figures 4, 5).<sup>23</sup>

Heated and cooled air produced by a GHP system is delivered through the house's ductwork in the same manner as conventional systems. A box called an air handler includes an indoor coil and fan that circulates house air through the heat pump for heating or cooling. Similar to a standard air conditioner, the air handler has a large blower and filter.



Image 4: Geothermal Heating System

Source: National Renewable Energy Laboratory Photographic Information Exchange.  
[http://www.nrel.gov/data/pix/searchpix\\_visual.html](http://www.nrel.gov/data/pix/searchpix_visual.html)

<sup>18</sup> A geothermal heat pump can also be referred to as GeoExchange, earth-coupled, ground source, or water-source heat pump.

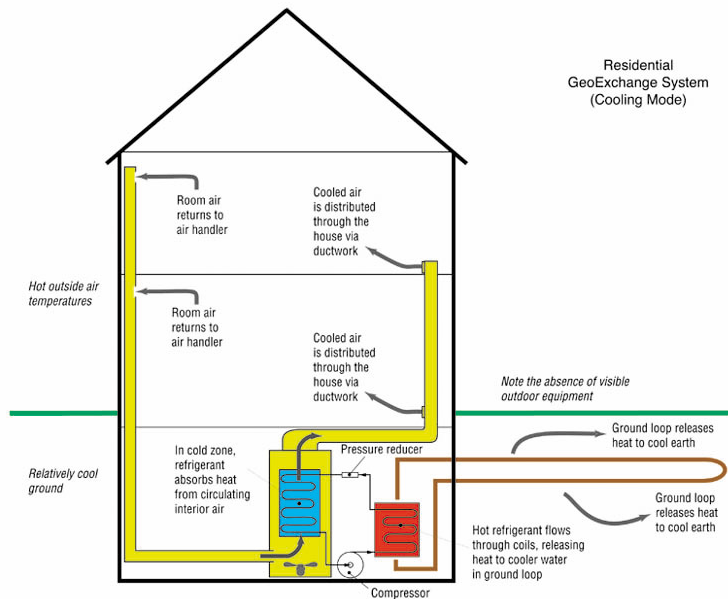
<sup>19</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12640](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640)

<sup>20</sup> [http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)

<sup>21</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12640](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640)

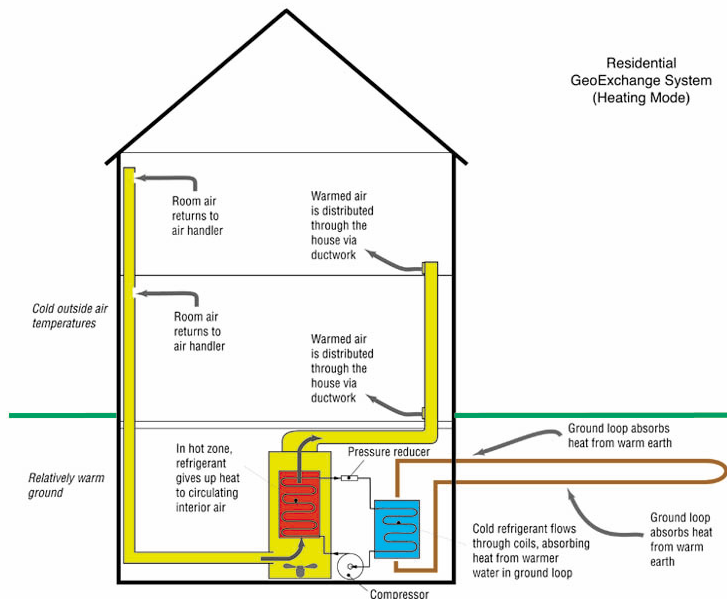
<sup>22</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12530](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530)

<sup>23</sup> [http://www1.eere.energy.gov/geothermal/geothermal\\_basics.html](http://www1.eere.energy.gov/geothermal/geothermal_basics.html)



**Figure 4. Residential GeoExchange System Cooling Mode.**

Source: GeoExchange.org.  
[http://www.geoexchange.org/index.php?option=com\\_phocadownload&view=category&id=3:residential-illustrations&Itemid=24](http://www.geoexchange.org/index.php?option=com_phocadownload&view=category&id=3:residential-illustrations&Itemid=24)



**Figure 5. Residential GeoExchange System Heating Mode.**

Source: GeoExchange.org.  
[http://www.geoexchange.org/index.php?option=com\\_phocadownload&view=category&id=3:residential-illustrations&Itemid=24](http://www.geoexchange.org/index.php?option=com_phocadownload&view=category&id=3:residential-illustrations&Itemid=24)

It should be noted that the initial purchase and installation price of a residential GHP is significantly higher than a comparable gas furnace or central air-conditioning unit. However, GHPs are much more efficient and overtime they will save the homeowner money in operating and maintenance costs. On average, the initial investment in a geothermal system is paid back through energy cost savings over a two to ten years period. The average system life is twenty-five years for inside components and more than fifty years for the ground loop system.<sup>24</sup>

### Geothermal Heat Pump System Parts and Types

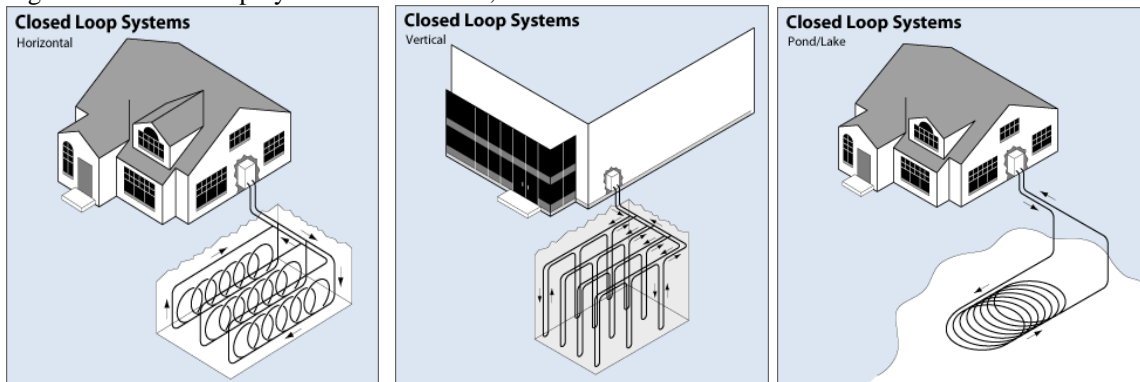
There are three basic parts to a GHP system: the geothermal connection, the heat pump, and the heat distribution system. The geothermal connection is a system of pipes (the “loop”) that in most systems are buried either horizontally or vertically underground near the connected building. Within the geothermal loop, a solution consisting of water, or a water/antifreeze mixture circulates and absorbs or releases heat to the underground soil depending on the difference between temperatures above and below ground. The purpose of the geothermal heat pump is to remove heat from the circulating fluid in the connection, condense it, and move it to the building. The opposite process occurs for cooling. Finally, the geothermal

<sup>24</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12640](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640)

heat distribution system is generally made up of conventional ductwork to carry heated or cooled air within a building.<sup>25</sup>

There are two main types of ground source geothermal systems: open-loop systems and closed-loop systems. Closed loop systems can be further divided into horizontal, vertical, or water-based installations (Figure 6).<sup>26</sup>

Figure 6. Closed Loop Systems – Horizontal, Vertical and Pond/Lake



Source: DOE

[http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12650](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650)

A horizontal closed loop system is the most common set up and generally the most economical option for residential applications (especially for new construction with adequate land available). These systems include high-density polyethylene piping that is buried in trenches 4-6 feet underground in a horizontal pattern. The pipes are filled with an antifreeze and water mixture that acts as a heat exchanger that extracts heat from the ground to the building in the winter, and it takes heat from the building and transfers it to the cooler ground in the summer.<sup>27</sup>

Vertical closed loop systems are typically most appropriate for commercial buildings or other large buildings (e.g., schools) where land space is limited or areas where soil is too shallow to dig trenches. Vertical systems are made of piping that extend 100-400 feet deep underground and are combined with a U-bend to form a loop.<sup>28</sup>

Closed loop systems that are connected to a pond or lake can be the most economically viable option when the site has a sufficient body of water. This system involves running a pipe-system underground (e.g., eight feet deep) between the building and under the water in a coiled pattern that helps prevent freezing during the winter.<sup>29</sup>

<sup>25</sup> <http://www1.eere.energy.gov/geothermal/heatpumps.html>

<sup>26</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12650](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650)

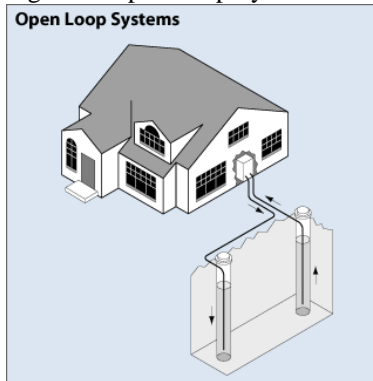
<sup>27</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12670](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12670)

<sup>28</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12650](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650)

<sup>29</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12650](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650)



Figure 7. Open Loop Systems



Source: DOE

[http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12650](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650)

Open loop systems use a water source (groundwater or a surface body of water) as the source of heat exchange. This option is most appropriate only when there is a sufficient source of clean water and water codes and regulations related to groundwater discharge are met. The water moves through the GHP system and then returns through a well, recharge well, or surface discharge.<sup>30</sup> Open loop systems can have negative environmental impacts such as warming surface waters and lowering water oxygen levels.<sup>31</sup>

## Geothermal Heat Pump Pros and Cons

There are several benefits and positive attributes of geothermal heat pumps that make them attractive alternative or supplemental heating and cooling systems. There are also several potential drawbacks and considerations that should be addressed before deciding to install a GHP.

### Geothermal Heat Pump Pros:

- 300-600% energy efficient
- 25-50% less electricity consumption compared to other types of systems
- Less expensive to operate and maintain compared to conventional heating and air conditioning systems with annual energy savings between 30-60% per year
- Reduced air emissions (e.g., pollution) by 44% as compared to conventional air-source heat pumps and 72% in comparison to standard electric heating with air-conditioning systems
- Can be scaled for use in residential and commercial buildings of all sizes
- Flexible design allows for new and retrofit installations
- System takes up less space compared to standard systems
- Quiet and very little noise compared to conventional air conditioners
- GHPs can maintain 50% relative indoor humidity and are appropriate for zone heating and cooling
- System life for a GHP is generally greater than 20 years and underground piping generally warranted between 25-50 years<sup>32</sup>

<sup>30</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12650](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650)

<sup>31</sup> "Well Management Geothermal Heating and Cooling Systems." [Minnesota Department of Health](#).

<sup>32</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12640](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640)

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### Geothermal Heat Pump Cons:

- Initial purchase and installation of GHPs is generally more expensive than conventional heating and cooling systems
- Potential negative environmental effects if installed or operated improperly
- Groundwater/environmental contamination in the event of a pipe leak<sup>33</sup>

As was mentioned earlier, GHPs can be installed almost anywhere in the US because of relatively constant ground temperatures. However, this is not to say that a GHP can be installed without any planning. Geology, hydrology, and land availability are all factors that should be evaluated before installing a GHP. Regarding geology, oil and rock composition and properties should be considered when designing a ground loop system because they can influence heat transfer rates. Surface water depth, volume, and quality are all factors that influence how bodies of surface water can be used as an open-loop system's water source or as a container for piping in a closed-loop. Regarding land availability, the amount, layout, and landscaping of the land where the GHP system will be installed should also be considered when designing a system.<sup>34</sup>

Because of the specialized knowledge, equipment, and skills required to properly install a GHP system, it is recommended that homeowners not try to install a GHP on their own, but instead work with a certified and experienced installer. Professional installers can be located by contacting the local utility company, the International Ground Source Heat Pump Association, or the Geothermal Heat Pump Consortium; all can provide a listing of qualified installers in a local area.<sup>35</sup>

### Conclusion

During a time of volatile energy costs and growing concerns over the effects of fossil fuel use, geothermal energy has great potential as a resource that is both environmentally and economically viable. Geothermal resources can be used in a wide variety of applications from melting snow on sidewalks to generating electricity. Geothermal heat pumps are a high-efficiency means of heating and cooling buildings. With careful planning, they can be installed almost anywhere and can provide homeowners with significant annual energy savings. Although geothermal energy is not the sole renewable energy solution, it can play a significant role in helping to meet the heating, cooling, and energy needs of communities across the US.

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<sup>33</sup> "Well Management Geothermal Heating and Cooling Systems." Minnesota Department of Health.

<sup>34</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12670](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12670)

<sup>35</sup> [http://www.energysavers.gov/your\\_home/space\\_heating\\_cooling/index.cfm/mytopic=12670](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12670)

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