THE HEAT IS ON: GEOTHERMAL HEATING AND COOLING SYSTEMS

BY

Tamarah Zipporah Bossewitch

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Abstract

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by Tamarah Zipporah Bossewitch

Chairperson of the Supervisory Committee: Dallas Abbot
Department of Environmental Science

__ABSTRACT:__

Geothermal-ground-source heat pumps are self-contained systems in which the heat pump is housed entirely within the building and connected to the outside via a buried ground loop. The geothermal heat pump (GHP) works to bring heat into the house during the winter, and drive heat out of the house, (effectively cooling), during the summer. The excess heat from the heat pump can be used to heat water, further saving money. Geothermal heat pump technology offers benefits to consumers, utility companies, and the environment. Ground source heat pumps offer consumers a heating, cooling, and hot water system that is cost-saving, reliable, efficient, and environmentally sound. The unique flexibility of ground-source heat pumps allows them to be used for residential and commercial buildings all across the U.S., Canada, and Europe. These heat pump systems can be installed in new buildings or as retrofits in older buildings. Ground source heat pumps systems help electric utilities stabilize demand loads and are therefore very competitive with other energy sources. GHP systems are a proven technology, and are fast becoming "the most reliable and competitive heating system available."[1] Geothermal Heat Pumps work with the environment to provide clean, efficient, and energy saving heating and cooling year round. Ground source heat pumps use less

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[1] Do It Naturally! Heat and Cool Your Home or Business with Geothermal/Ground Source Heat Pumps, IGSHPA, Oklahoma State University . 8 January 2000 <http://www.igshpa.okstate.edu/publications/Brochures/Do_It_Naturally/din.html.>.

energy than alternative heating and cooling systems, helping to conserve our natural resources. Finally, GHP systems are quiet, pollution free, and do not detract from the surrounding landscape.

In this report I will explain the way a geothermal heat pump works. I will then compare geothermal systems with conventional heating and cooling systems. Subsequently, I will explore the advantages of geothermal heat pumps, using cost-savings analysis, energy usage, as well as efficiency comparisons. Finally, I will present a site-specific case study of a geothermal heat pump system that is currently in use at the Black Rock Forest Center for Science and Education. Through a series of calculations and graphs based on the monitoring sensors located at the Black Rock Forest Center, I will examine the actual efficiency and feasibility of a geothermal heating and cooling system.

The main findings of the case study at Black Rock forest showed an actualization of the projected savings. Though the data is at present limited, we can expect future trends to show increased energy savings, a payback time of around four years, and continued comfort and satisfaction through the use of this geothermal heat pump.

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Chapter 1

BACKGROUND INFORMATION ON GEOTHERMAL HEATING AND COOLING SYSTEMS

"Geothermal energy results from heat stored in rock by the earth's natural heat flow which (a) is highly concentrated in high-enthalpy regions at volcanically active plate margins; (b) is sufficiently concentrated in the low-enthalpy resources of sedimentary basins with shallow rock strata that conduct a low amount of heat energy; or (c) is potentially concentrated enough for exploitation in certain granite areas where heat may be extracted by opening up pre-existing joints of hot dry rocks."[2]

There are two types of geothermal energy, and it is important to distinguish between them. The first type is called High-Temperature Geothermal Energy. In this type of system, steam is used to generate power. When this is done, the waste heat can be used for space- heating. In these systems, geothermal heat is extracted faster than it is replaced, and thus can be considered "heat mining." The second type of geothermal energy that is available to us is via a Geothermal Heat Pump (GHP). A geothermal heat pump uses a heat pump to utilize the ground temperature in the earth for residential or industrial heating or cooling. This type of system is entirely renewable, and represents an indefinite source of energy. In this paper, I will explore the details and implications of geothermal heat pumps for use in our everyday lives.

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2 Godfrey Boyle, Renewable Energy: Power for a Sustainable Future (United Kingdom: Oxford University Press, 1996) 353.

Heat Pumps: How They Work:

Though the term "heat pump" itself may be unfamiliar, the operation of a heat pump is familiar to anyone who has a refrigerator or an air conditioner. Rather than producing heat, a heat pump is a device that takes up heat at a certain temperature and releases this heat at a higher temperature. When operated to provide heat, for space or water heating, the heat pump is said to operate in the heating mode; when operated to remove heat, for air-conditioning, it is said to operate in the cooling mode.[3] An air-source heat pump extracts heat from outdoor air and pumps it into the house. A ground-source heat pump operates in the same manner, but rather than extracting heat from outdoor air, it absorbs thermal energy stored in the earth and/or the earth's groundwater. "The moderate, relatively constant temperature of the earth is an attractive advantage of ground-source heat pumps over air-source units. In New York State, for example, groundwater/earth temperatures average a fairly steady 50'F, whereas air temperatures average less than 40'F and frequently plummet to below freezing during the heating season."[4]

Heat Transfer Cycle:

> "Every GeoExchange System has three major subsystems or parts: a geothermal heat pump to move heat between the building and the fluid in the earth connection, an earth connection for transferring heat between its fluid and the earth, and a distribution subsystem for delivering heating or cooling to the building. Each system may also have a

[3] Heat Pump Systems: a Technology Review, p. 17 by: International Energy Agency, 1982 **(ask dallas how to footnote/endnote)**

[4] New York State Energy Research and Development Authority. A Technical Guide to Ground Source Heat Pumps. (New York: [1998?]) 3.

desuperheater to supplement the building's water heater, or a full-demand water heater to meet all of the building's hot water needs."[5]

The process of elevating low-temperature heat to over 100'F and transferring this heat to indoor air involves a cycle known as the heat transfer cycle. This cycle includes evaporation, compression, condensation and expansion. A refrigerant is used as the heat-transfer medium that circulates through the heat pump system.

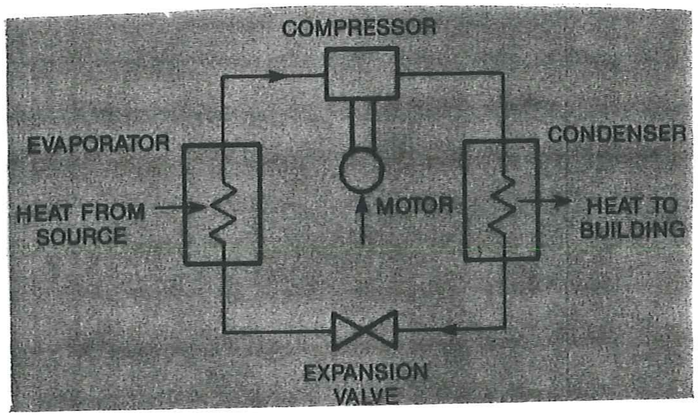

Figure 1: Heat Transfer Cycle

As shown in **Figure 1**[6], "the cycle starts as the cold, liquid refrigerant passes through a heat exchanger (evaporator) and absorbs heat from the low-temperature source. The refrigerant evaporates into a gaseous state as heat is absorbed. The gaseous refrigerant then passes through a compressor where the refrigerant is pressurized and, as a result, its temperature is increased. The hot refrigerant gas then circulates through a refrigerant-to-air heat exchanger (condenser) where heat is removed from the refrigerant and transferred to interior air. The refrigerant reverts back to

[5] How Does GeoExchange Work? GeoExchange Heating and Cooling, GeoExchange, 11 November 1999, <http://www.geoexchange.org/public/how_it_works.html >.

a liquid as it cools in the condenser, then passes through a refrigerant flow restrictor which acts as an expansion device (pressure reducer), cooling it. Now at a lower temperature and pressure, the cold refrigerant is returned to a starting point and the cycle is repeated. When the heat pump is equipped with a reversing valve, the cycle can be changed to provide summer air conditioning by effectively reversing the roles of the evaporator and condenser coils.[7]

HEATING AND COOLING:

In the heating mode, heat is extracted from the fluid in the earth connection by the geothermal heat pump and distributed to the home or building. As this happens, cooler air from the home or building is pushed out, and returned to the geothermal heat pump, where it cools the fluid flowing to the earth connection. During the summertime, the process is reversed. The relatively cool fluid from the earth connection absorbs heat from the building and transfers it to the ground. This process creates central air conditioning **(Figure 2).** [8]

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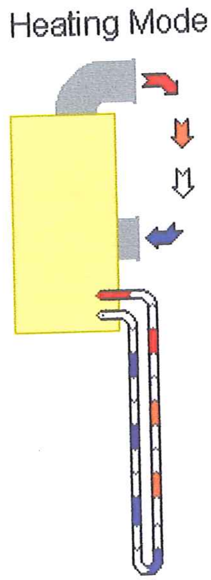
6 New York State Energy Research and Development Authority. A Technical Guide to Ground Source Heat Pumps. (New York: [1998?]) 2.

7 New York State Energy Research and Development Authority. A Technical Guide to Ground Source Heat Pumps. (New York: [1998?]) 2.

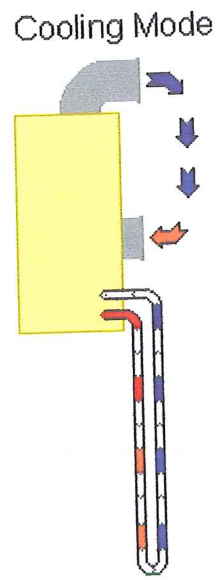
8 How Does GeoExchange Work? GeoExchange Heating and Cooling, GeoExchange, 11 November 1999, <http://www.geoexchange.org/public/how_it_works.html >.

FIGURE 2: HEATING AND COOLING MODE OF GEOTHERMAL HEAT PUMPS[9]



In heating mode, heat is extracted from the fluid in the earth connection by the geothermal heat pump and distributed to the home or building -- typically through a system of air ducts. Cooler air from the building is returned to the geothermal heat pump, where it cools the fluid flowing to the earth connection. The fluid is then re-warmed as it flows through the earth connection.

In cooling mode, the process is reversed. The relatively cool fluid from the earth connection absorbs heat from the building and transfers it to the ground.



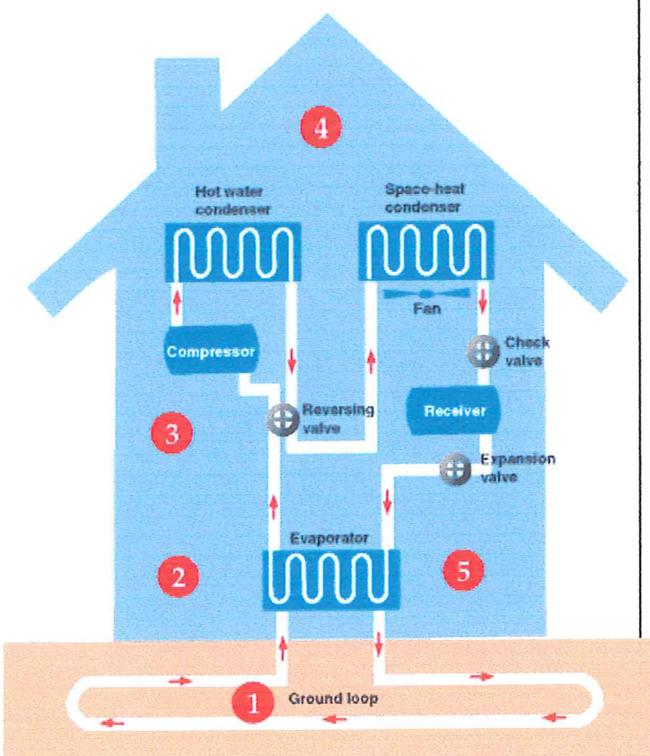
[9] How Does GeoExchange Work? GeoExchange Heating and Cooling, GeoExchange, 11 November 1999, <http://www.geoexchange.org/public/how_it_works.html >.

Figure 3: How Does a GHP System Work?[10]

-How It Works-

Ground-Source Heat Pump

A GROUND-SOURCE heat pump is essentially an air conditioner that also runs backward: In winter, it extracts heat from the ground for heating. Used for decades, these machines heat more efficiently than most other systems. Put one unit of energy into a furnace, for instance, and you get somewhat less than one back out as heat. But put that unit into a heat pump, and you more than triple the return. That's because heat pumps don't use energy to create heat; instead, they move heat that already exists. -Mariette DiChristina



1 -Ground source heat pumps start with a closed loop of buried pipes containing a fluid that can carry heat. The pipes may lay in shallow long curved trench, or they may jut deep into the ground.

2 -For heating (shown), the pipe fluid absorbs heat from the earth. The fluid passes through a heat exchanger (acting as an evaporator), where it transfers heat to a refrigerant.

3 -The refrigerant, which flows through another closed loop in the heat pump, then boils. The vaporized refrigerant travels to the compressor, where its temperature and pressure are increased.

4 -The hot gas continues to two heat exchangers (acting as condensers), one to heat the house's water and the other for space heating. At each, the refrigerant gives up some heat. A fan blows across the space-heat condenser to move the warmed air through the house. The refrigerant, again a liquid, repeats the process.

5 -In summer, the cycle reverses to remove heat from the house. Some of the heat is used for hot water; the remainder is dumped into the earth via the ground loop.

[10] Cecilia Wessner, "How It Works," Popular Science Magazine, Feb. 1996,. 73.

MAKING HOT WATER:

Ground source heat pumps are available with an optional *desuperheater* (see **Figure 4**), which siphons off some hot refrigerant to a secondary heat exchanger for domestic water heating. A desuperheater is a small, auxiliary heat exchanger that uses superheated gases from the heat pump's compressor to heat water. In summer, when the system is in the cooling mode, the desuperheater merely uses excess heat that would otherwise be expelled to the loop. In the cooling mode, this surplus heat provides free hot water. A conventional water heater meets household hot water needs in winter if the desuperheater isn't producing enough. In the winter heating mode, the desuperheater reduces water-heating costs. The combined summer and winter use of a desuperheater provides overall savings of 60% on annual water-heating bills.

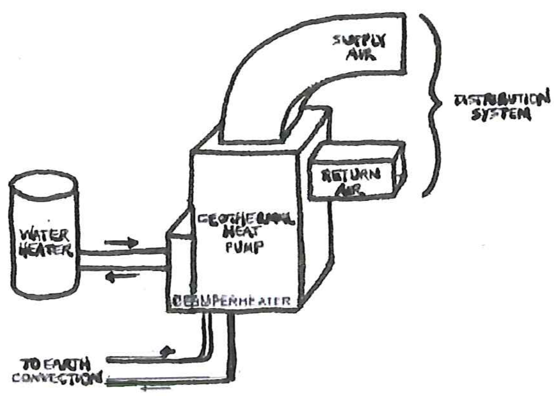


FIGURE 4: MAKING HOT WATER: DESUPERHEATER[11]

[11] Residential Heating and Cooling Story, GB-001, GeoExchange, 1 January 2000 <http://www.geoexchange.org/public/segment/residentaial.htm>.

GROUNDWATER AND EARTH-COUPLED SYSTEMS:

The earth stores solar energy deep in the ground, where it is insulated from seasonal temperature changes. As a result, earth and groundwater temperatures stay considerably constant throughout the year. On the other hand, there is high variability of the ambient air temperature.

Groundwater aquifers and earth-coupled loops are the two energy sources used in ground-source heat pump installations. There are two basic types of loop systems: an open-loop system, and a closed-loop system.

An open-loop system is also known as a ground water heat pump system. Groundwater heat pump systems use well water as the low temperature heat source. The water is removed from the aquifer, passes through a liquid-to-refrigerant heat exchanger in the heat pump, and then is returned to the aquifer. At this point, the water is discharged into a stream or pond, or used for other purposes.

Closed-loop systems, also known as earth-coupled heat pump systems, use earth loops, or pipes, which are buried in the ground. Sometimes, horizontal loops are submerged in lakes or ponds where they utilize the heat stored in the water. Earth loops can be laid horizontally in trenches, or inserted vertically into drilled holes.

In the horizontal system, a ground coil is buried in a 2.5 ft. to 6 ft. trench. An environmentally friendly antifreeze solution circulates through this coil in order to absorb the heat from the earth. After passing through the ground coil, the antifreeze moves through a liquid-to-refrigerant heat exchanger where it exchanges heat with the refrigerant. The vertical earth loop system can be installed in vertical holes, and therefore minimizes the site area requirements. The vertical loop system is designed to accomplish the same result as the ground coil system.

Since both have similar performance, the main consideration in choosing which type of loop system is the installed cost. The basic horizontal configuration uses one pipe per trench, and can be installed in series (**Figure 5**) or in parallel. The second configuration, uses two pipes per trench, and can also be installed in series or parallel (**Figure 6**). The vertical earth loop, shown in (**Figure 7**), has a parallel pipe configuration that allows smaller pipe and bore diameters.

Horizontal loops are often considered when adequate land surface is available. Pipes are placed in trenches, in lengths that range from 100 to 400 feet. Vertical loops are the best choice when the available land surface is limited. Drilling equipment is used to bore small-diameter holes from 75 to 300 feet deep. Finally, pond or lake loops are very economical to install when a body of water is available, because excavation costs are eliminated. In this case, coils of pipe are placed on the bottom of the pond or lake.[12]

[12] Geothermal Heat, Waterfurnace International, Inc., 5 October 1999 <http://www.waterfurnace.com/geotherm.html>.

FIGURES 5, 6, AND 7: VERTICAL AND HORIZONTAL EARTH LOOP SYSTEMS[12]

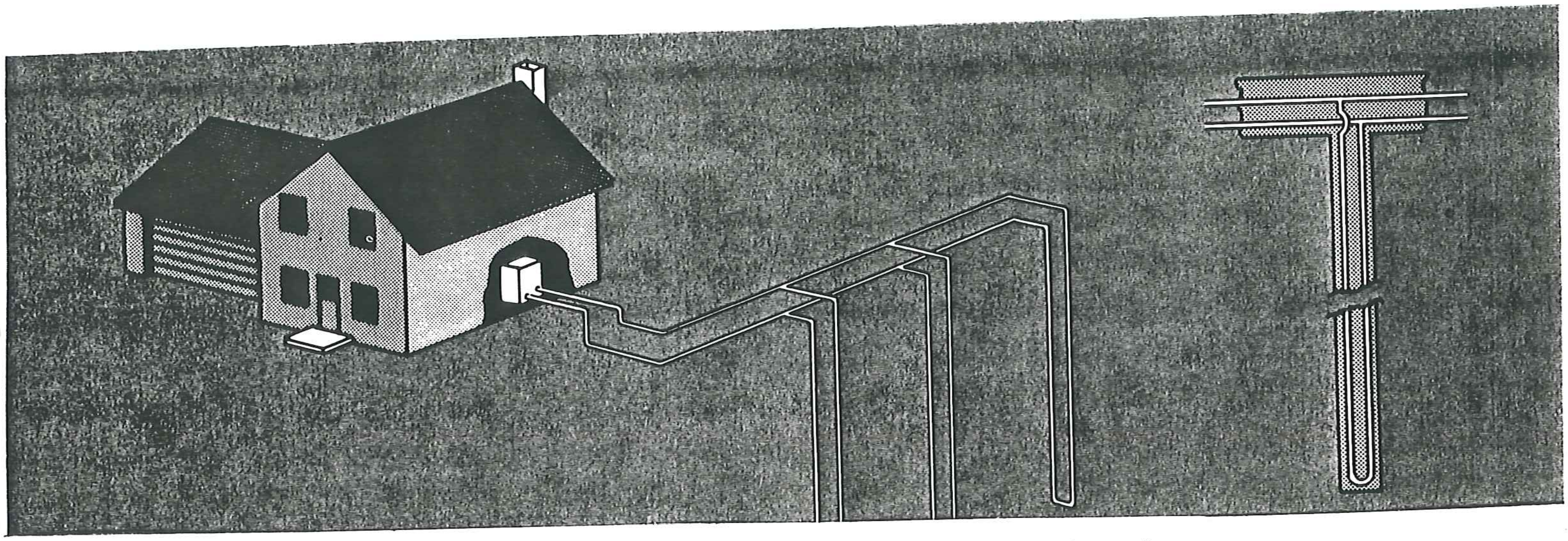


Figure 5. Vertical Earth Loop—Multiple-Bore Parallel Configuration

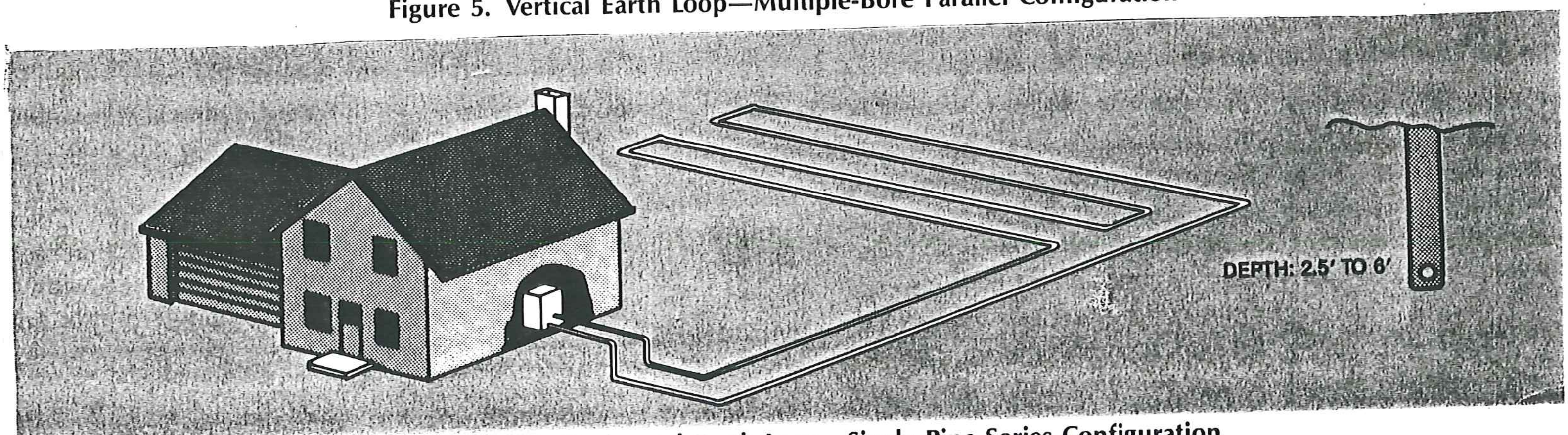


Figure 6. Horizontal Earth Loop—Single-Pipe Series Configuration

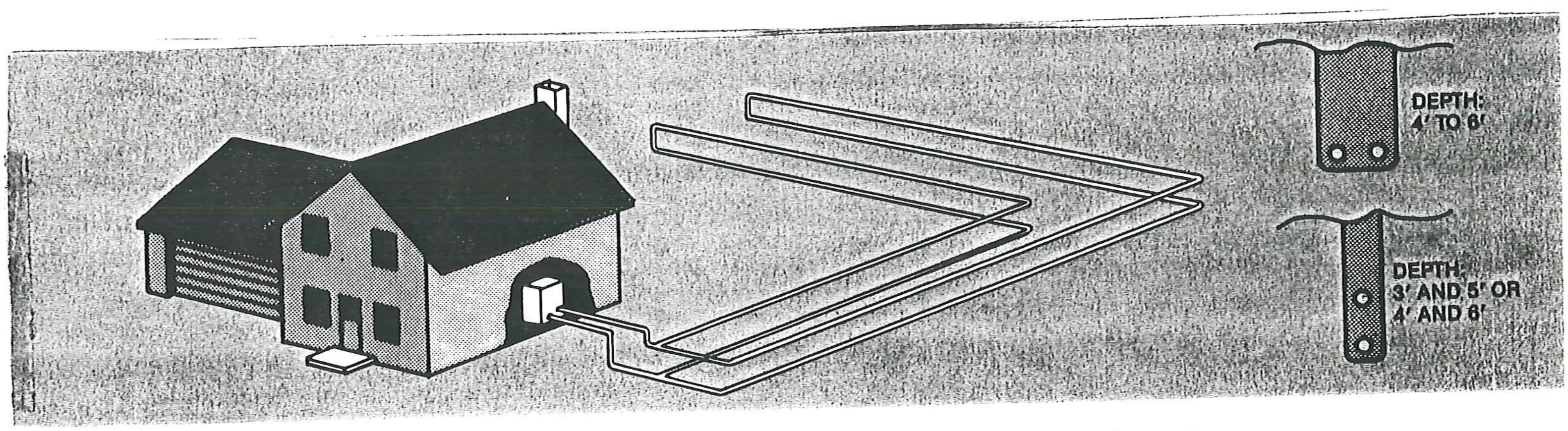


Figure 7. Horizontal Earth Loop—Double-Pipe Parallel Configuration

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13 New York State Energy Research and Development Authority. A Technical Guide to Ground Source Heat Pumps. (New York: [1998?]) 7.

"Current research confirms that 400 to 450 trench feet per nominal ton of heat pump capacity is adequate for the basic 1 to 1.5 inch diameter one-pipe-per-trench horizontal configuration. Research also indicates that the two-pipe-per-trench horizontal system can be sized at 250 to 300 trench feet per ton. Vertical parallel systems can be sized at 125 to 175 feet of vertical bore per ton.

The best configuration is one that can be installed for the least cost at a particular site. When sized properly, all configurations should result in similar system performance."[14]

Moisture migration is an important factor that affects the heat transfer of the closed loop system. Heat transfer is improved between the earth loop and the surrounding soil when heat is extracted from the earth, and soil moisture migrate toward the loop. "As loop temperatures drop below freezing, latent heat of fusion is given up and the soil moisture freezes, further improving heat transfer. The latent energy given up during freezing and the improved heat transfer of the frozen soil prevent properly sized earth loop source temperatures from dropping below 25′ to 30′F under any conditions, while outdoor air can plunge to 20′F below zero."[15]

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14 New York State Energy Research and Development Authority. A Technical Guide to Ground Source Heat Pumps. (New York: [1998?]) 6.

15 New York State Energy Research and Development Authority. A Technical Guide to Ground Source Heat Pumps. (New York: [1998?]) 7.

Geothermal Heat Pumps Vs. Conventional Systems:

According to the Water Furnace International, Inc., "Geothermal is the safest, cleanest, most reliable space conditioning system you can buy."[16]

GHP systems can be used for many different types of buildings. The benefits that many residential consumers receive can also be realized by commercial and government organizations. Hospitals, schools, museums, low-income housing projects, government buildings, and small and large commercial buildings can benefit. In order to compare geothermal heat pumps with traditional space heating systems we must consider the following aspects of each system:

- Start-up costs, long term cost savings
- Performance and efficiency
- Long and short term maintenance
- Environmental Impact

Even though a geothermal system is "the most efficient method available to provide year round comfort and high efficiency performance,"[17] this technology is not as widespread as it should be. Jim Bose, executive director of the ten-year-old International Ground-Source Heat Pump Association (IGSHPA), believes that,

> The main obstacle to expanding the market is lack of awareness of the technology, but initial costs also affect market growth. Equipment prices run

16 Geothermal Heat, Waterfurrnace International, Inc., 5 October 1999, <http://www.waterfurnace.com/geotherm.html>.

17 How Does Geothermal Heating and Cooling Work? Climatemaster, 5 October 1999 <http://www.climatemaster.com/geothermal.html >.

high compared to conventional heat pumps, and the ground-loop drilling or trenching adds to the installation costs."[18]

In order to counteract the initial start-up costs, incentives are being created to corner the market, and take advantage of geothermal technology. In 1993, the national Geothermal Heat Pump Consortium was formed. It includes DOE, EPA, EPRI, IGSHPA, Edison Electric Institute, National Rural Electric Co-op Association, and manufacturer representatives. Lew Pratsch, the Department of Energy (DOE) senior program manager, said that the key goals of the consortium are "to get utilities more involved, create market incentives, and find ways to reduce the cost and time of installation, which will involve getting more work for installation crews, finding ways to reduce the size of the ground loop to expand the market for urban lots, and obtaining more data for utilities to justify incentive programs."[19]

Pratsch believes that ground-source heat pumps can be tied into building envelope improvements in retrofit applications. A study in California compared ground-source heat pumps with conventional HVAC appliances in six locations statewide. "Results favored use of ground-source heat pumps in four of the six areas, for both retrofit and new construction. Adding a water-heating option would make all six locations cost-effective in new construction, and five of the locations favorable for

[18] Ted Reiger, "Ground Source Heat Pumps Gaining Ground" Home Energy Magazine Online. July/August 1994. <http://hem.dis.anl.gov/eehem/94/940703.html>.

[19] Ted Reiger, "Ground Source Heat Pumps Gaining Ground" Home Energy Magazine Online. July/August 1994. <http://hem.dis.anl.gov/eehem/94/940703.html>.

retrofits. Utility rebates and incentives would further enhance the economics for consumers."[20]

David Maul, a committee member of the California Energy Committee (CEC), said, "ground-source heat pumps have the potential to significantly reduce total energy consumption for home heating and cooling in California. However, overall economic feasibility and cost-effectiveness will be closely tied to actual installed costs. Market demand and competition is critical in order to bring manufacturers here with competitive unit prices, and to bring down the average cost currently charged by well-drilling companies for drilling."[21]

At one point, GHP systems were only considered an option for extremely wealthy clients. However, today, homeowners in all income brackets can take advantage of the benefits of GHP heating and cooling. Initial costs have declined substantially as many more builders and heating and cooling contractors nationwide make the GeoExchange systems available. Furthermore, innovative techniques enable the loops to be installed more quickly, often in one day, lowering the costs. Additionally, some electric utilities around the nation now have incentive programs and low-interest financing programs that can make GeoExchange even more affordable. Many financial institutions now allow home buyers to qualify for larger mortgages if they purchase

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20 "Economic Assessment of Geothermal Heat Pumps in the State of California (Phase 1 Activity)," December 1993, presented by the Fleming Group, Inc., East Syracuse, New York. Tel: (315) 437-1869.

21 "Economic Assessment of Geothermal Heat Pumps in the State of California (Phase 1 Activity)," December 1993, presented by the Fleming Group, Inc., East Syracuse, New York. Tel: (315) 437-1869.

house that utilizes a GHP system. The reduction in monthly energy bills more than offsets the slightly higher mortgage payments. [22]

COST-SAVINGS ANALYSIS OF GEOTHERMAL HEATING AND COOLING SYSTEMS:

When comparing the costs of different systems, we need to consider safety, installation costs, maintenance costs and comfort. To simplify the selection process, the installation, operating and maintenance costs can be combined into a life-cycle-cost. This is defined as the cost of ownership over a period of years. The following table, compiled in 1999 by the Geothermal Heat Pump Consortium, compares various types of central heating systems. [23]

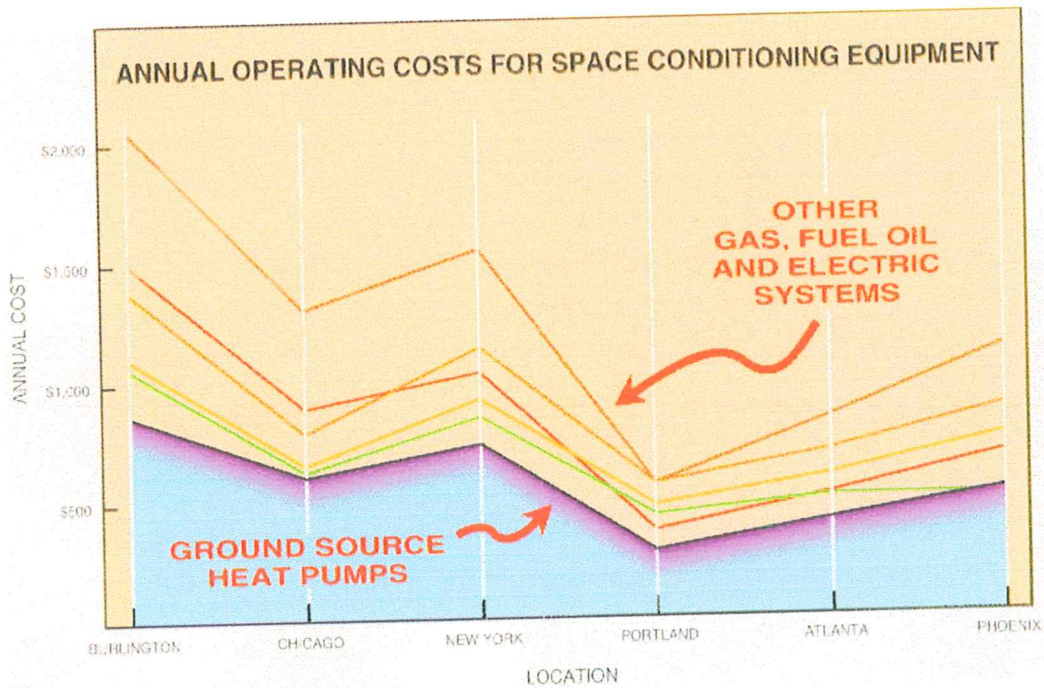
	Safety	Installation Cost	Operating Cost	Maintenance Cost	Life-Cycle Cost
Combustion-based	A Concern	Moderate	Moderate	High	Moderate
Non-combustion					
Heat pump	Excellent	Moderate	Moderate	Moderate	Moderate
GeoExchange℠	Excellent	High	Low	Low	Low

TABLE 1: VARIOUS TYPES OF CENTRAL HEATING SYSTEMS

[22] The Residential GeoExchange Heating and Cooling Story, GeoExchange, 9 November 1999 <http://www.geoexchange.org/public/segment/residential.html.>.

[23] Geothermal Heat Pump Consortium, Inc. 1999, 1 November 1999, <http://www.geoexchange.org/public/series/compare.html>.

The IGSHPA table of Annual Operating Costs for Space Conditioning also illustrates the savings which GHP systems provide for consumers.[24]



<u>TABLE 2:</u> ANNUAL OPERATING COSTS FOR SPACE CONDITIONERS

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[24] Do It Naturally! Heat and Cool Your Home or Business with Geothermal/Ground Source Heat Pumps. IGSHPA, Oklahoma State University, 1 November 1999 <http://www.igshpa.okstate.edu/publications/Brochures/Do_It_Naturally/din.html.>.

A further analysis provided in the 1993 EPA report: Space Conditioning: The Next Frontier,[25] shows a more detailed table of annual operating costs for space heating and cooling.

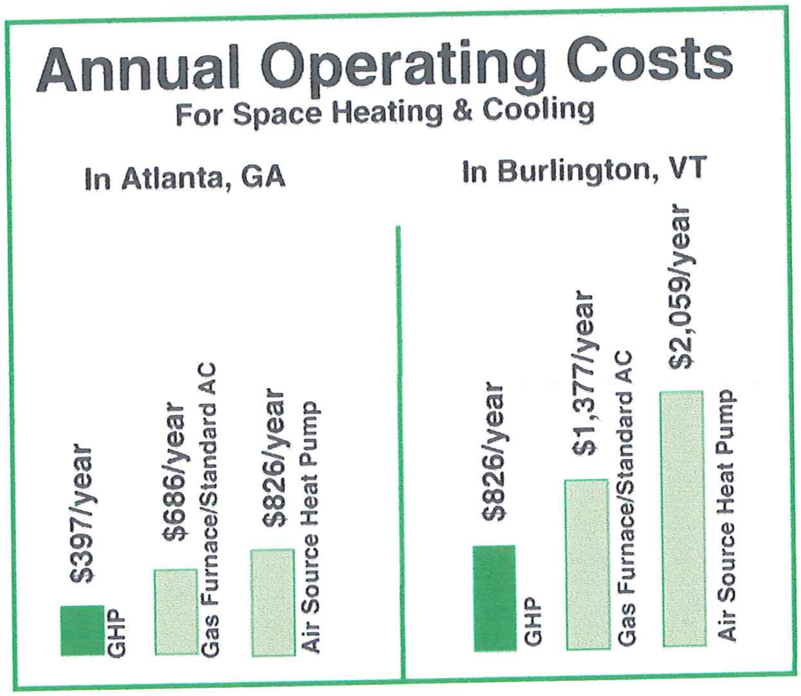

TABLE 3: ANNUAL OPERATING COSTS FOR SPACE HEATING AND COOLING

A recent study by the U.S. Environmental Protection Agency showed that GeoExchange[SM] systems generally have the lowest life-cycle cost of all systems available today. The study also shows that GeoExchange[SM] systems have the lowest impact on our environment. And consumers rank their comfort and satisfaction with GeoExchange[SM] systems higher than all

[25] Environmental Protection Agency, Space Conditioning: The Next Frontier, Office of Air and Radiation, 430-R-93-004 (4/93).

others. While a higher initial investment is required, the investment is paid back through low energy bills (enhancing resale value), excellent family safety, and real comfort.[26]

In light of the lower annual operating costs of a GHP system, even though a GHP system usually costs a few thousand dollars more than more than the typical space heating and cooling system, "most GHP homeowners will save more money on their utility bills each month than the extra loan payments. This gives home-owners a positive cash-flow each month."[27]

The following data was collected by the IGSHPA. It is an example of the financing options that are available. In this scenario, a family of four lives in a 2,000 square foot home with an electric heat and air system that needs to be replaced. Upon checking into their replacement options, the family discovers that a GHP installation is going to cost $5,750.00. However, their local utility company offers a rebate of $250.00 per ton; this equals $750.00 on a 3-ton-installation.

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26 Environmental Protection Agency, Space Conditioning: The Next Frontier, Office of Air and Radiation, 430-R-93-004 (4/93).

27 Financing Your Geothermal Heat Pump, IGSHPA, Oklahoma State University, 1 November 1999 <http://www.igshpa.okstate.edu/technology/MoreInfo/FactSheet/FinanceFactSheet.html>.

Table 4: Financing Options

GHP installation	$5,750.00
Rebate	-750.00
Amount to finance	**$5,000.00**

They can finance the remaining cost of equipment and installation ($5,000) through their local utility at 5% for seven years.

Amount to finance	$5,000.00
@ 5% for 7 years	
Monthly loan payment	**$70.00**

The projected utility bill for the new system is $57 per month. Their bills averaged $137 a month using their old system. So the projected savings per month are $80.

Utility bill before	$137.00
Utility bill w/ GHP	-57.00
Monthly savings	**$80.00**

There is now a positive cash flow, since the savings on the utility bill exceed the GHP loan payment.

Monthly utility savings	$80.00
Loan payment on GHP	-70.00
Positive cash flow	**$10.00**

Although the GHP's initial cost is $2,000 higher than some other systems, it will save the family over $20,000 during its expected working life.

Savings in 25 years	$24,000.00
Incremental cost	-2,000.00
Amount of savings	$22,000.00

ENHANCED COMFORT AND APPEARANCE:

- GHP systems provide a constant, even temperature throughout the home, without any hot or cold spots; this creates comfortable heating in the winter, and cooling in the summer. There is also better humidity control in the summer.
- GHP systems are attractive and the self-contained indoor unit does not need any noisy or unsightly condensing unit.
- All of the heating, air conditioning, and hot water come from the same compact unit.
- GHP systems use a safe, non-combustion process for heating and cooling. This means that there is no flame, no odors, and once again, a quiet operation.

GREATER CONVENIENCE:

- No more fuel deliveries
- Simultaneous heating and cooling for different zones

ENVIRONMENTAL BENEFITS:

- GHP systems are renewable, environmentally friendly energy source. "GeoExchange heat pumps use the Earth's energy storage capability to heat and cool buildings, and to provide hot water. The earth is a huge energy storage device that absorbs 47% of the sun's energy-more than 500 times more energy than mankind needs every year- in the form of clean, renewable energy. GeoExchange heat pumps take this heat during the heating season at an efficiency approaching or exceeding 400%, and return it during the cooling season."[28]

- GHP systems reduce harmful emissions because there is not any on-site combustion of fossil fuels. According to IGSHPA, geothermal-ground-source systems lower the amount of greenhouse gas emitted by a house by ¾ ton each year. In addition, geothermal heat pumps work toward the preservation of the environment by minimizing present environmental problems like acid rain, air pollution, and the destruction of the ozone layer.

> Achieving the Geothermal Heat Pump Consortium's (GHPC) goal of 400,000 annual GeoExchange installations each year by 2001 will reduce U.S. greenhouse emissions by over 1 million metric tons of carbon each year relative to base case market projections. This reduction in carbon emissions is equivalent to taking over half a million cars off the road, or planting over a million acres of trees. After GHPC's program ends at that time, a self-sustaining GeoExchange industry will cause U.S. annual carbon emissions to decrease by an additional 450,000 tons- every year! That translates into a total annual carbon reduction of at least 5 million metric tons by the year 2010.[29]

- The EPA found that GeoExchange heat pumps can reduce energy consumption- and corresponding emissions- by over 40% compared to air source heat pumps and by over 70% compared to electric resistance heating with standard air-conditioning equipment.

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[28] Fascinating Facts: GeoExchange Heating and Cooling Systems, GeoExchange, 1 November 1999, <http://www.geoexchange.org/public/fasfact.html>.

[29] Fascinating Facts: GeoExchange Heating and Cooling Systems, GeoExchange, 1 November 1999, <http://www.geoexchange.org/public/fasfact.html>.

Combining GeoExchange with other energy-efficient measures, such as window or insulation upgrades, can increase these savings even further.

<u>LIFE SPAN AND DURABILITY OF GHP SYSTEM:</u>

Geothermal Heat Pump systems are very durable. They have fewer mechanical components making them more reliable and less prone to failure. Furthermore, all the components are either buried in the ground or located inside the home, which protects them from outside conditions. As a result, geothermal-ground-source heat pumps last longer than conventional systems and are very low maintenance. Usually, the underground pipe carries a 50-year warranty.

<u>BENEFITS TO CONSUMERS AND UTILITIES:</u>

- Surveys by utilities indicate a higher level of consumer satisfaction for GeoExchange heat pumps than for conventional systems. "Polls consistently show that more than 95% of all GeoExchange heat and cooling customers would recommend GeoExchange to a family member or friend."[30]
- Achieving GHPC's goal of 400,000 installations per year by 2001 will save consumers over $420 million per year in energy bills. After that, annual energy savings will increase by an additional $170 million – every year. "The U.S. general Accounting Office estimates that if

30 **<u>Fascinating Facts: GeoExchange Heating and Cooling Systems</u>**, GeoExchange, 1 November 1999, <http://www.geoexchange.org/public/fasfact.html>.

GeoExchange heat pumps were installed nationwide, they could save several billion dollars annually in energy costs."[31]

- GHP systems help electric utilities stabilize demand loads and become more competitive with other energy sources.
- Reduction in peak power loads.

EFFICIENCY OF GEOTHERMAL SYSTEMS:

According to the Environmental Protection Agency, GeoExchange systems save homeowners 30-70% in heating costs, and 20-50% in cooling costs, compared to conventional systems.[32] A geothermal system uses the Earth's thermal properties in conjunction with electricity to provide unprecedented efficiency. "For every unit of electricity the system uses, it provides four units of heating energy, giving a geothermal system a 400% efficiency rating on average."[33]

The EPA also found that even on a source fuel basis, accounting for ALL losses in the fuel cycle including electricity generation at power plants, GeoExchange systems are much more efficient than competing fuel technologies. "They are on an average of 48% more efficient than the best gas furnaces on a source fuel basis, and over 75% more efficient than oil furnaces. In fact,

31 Fascinating Facts: GeoExchange Heating and Cooling Systems, GeoExchange, 1 November 1999, <http://www.geoexchange.org/public/fasfact.html>.

32 The Residential GeoExchange Heating and Cooling Story, GeoExchange, 9 November 1999 <http://www.geoexchange.org/public/segment/residential.html.>.

33 Geothermal Heat, Waterfurrnace International, Inc., 5 October 1999, <http://www.waterfurnace.com/geotherm.html>.

today's best GeoExchange systems outperform the best gas technology, gas heat pumps, by an average of 36% in heating mode and 43% in cooling mode!"[34]

[34] **Fascinating Facts: GeoExchange Heating and Cooling Systems**, GeoExchange, 1 November 1999, <http://www.geoexchange.org/public/fasfact.html>.

Chapter 2

WORKING HYPOTHESIS: ACTUAL PERFORMANCE OF GEOTHERMAL HEATING SYSTEMS

In order to analyze the actual performance of the system we need to explore the factors that affect the efficiency of the system. These factors include the wind velocity, external and internal air temperature, water flow thru the pipes, and the heat exchange rate of the building. It is projected that the system is most efficient at the start of each summer and winter season. As the season moves on, the efficiency curve decreases. This happens because in the winter, excess cool air is extracted from the building and pushed towards the heat source in the ground; therefore, as winter moves on, the heat source becomes cooler. During the summertime, the opposite happens, and the "cool" spot in the ground warms up. It should be noted that the decreasing efficiency curve enables the system to be a more efficient cooler at the beginning of the summer, and a better heater at the beginning of winter.

SITE SPECIFIC DATA: CASE STUDY OF BLACK ROCK FOREST CENTER FOR SCIENCE AND EDUCATION:

The Black Rock Forest Center for Science and Education is located in Cornwall, NY. In addition to passing on knowledge and information about the natural world through its educational courses, it serves as an example of energy efficient, low-impact rural architecture. In order to design this energy efficient structure, the Black Rock Forest Consortium worked in alliance with: Fox and Fowle Architects, Steven Winter Associates (SWA), (an energy consulting firm), as well as the New York State Energy Research and Development Authority (NYSERDA).

> According to SWA principle Adrian Tuluca, "we proceeded under the assumption that a building dedicated to the study and appreciation of the natural world should itself serve as a model of environmentally sensitive design and engineering. It's my hope that visitors to Black Rock will come away with a sense of having been in a structure that's not only comfortable and aesthetically pleasing, but also one that treads lightly on the planet."[35]

When designing the 9,050 sq. ft. structure, SWA worked with Fox and Fowle to identify a number of specific energy efficient strategies that minimize energy consumption while delivering thermal comfort throughout the building. The design team's overriding strategy was to create a building whose envelope and shape are inherently efficient, and to minimize heat gains from lighting and computers. Special building components were chosen for their contributions to overall operating efficiency, and in some cases, for their positive effects on the indoor air quality. Incorporating certain strategies like these enable downsizing the mechanical equipment, which helps offset the cost of improved walls, windows, and the roof.

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[35] 'Whole Buildings' in a Black Rock Forest: Design Team Brings Passive Solar, Geothermal, & SIPs together Under One Roof, Steven Winter Associates, Inc., Press Release, April 9, 1999.

In order to identify efficient strategies, materials, and systems for the Black Rock Forest Center, computer analyses were conducted using a state-of-the-art energy performance stimulation program called DOE-2.1E.

" The purpose of the simulation was three-fold:

- Ascertain energy saving opportunities within a unified design that results in small first cost increments.
- Recommend building details that reduce the probability of moisture condensation.
- Achieve thermal comfort and good IAQ.

The guiding idea for the building was to achieve a high level of efficiency and good indoor air quality, at a relatively small increase in initial cost. To this end, the following strategy was pursued:

- Site the building with the long axis on an east-west direction, to take advantage of solar heat during winter, and to easily protect against solar heat during summer.
- Place most windows on south and north facades, for reduced solar gain in summer, increased solar gain in winter, and good cross-ventilation.
- Specify high R-glass, with high visible transmittance, but with low shading coefficient. Protect the windows on the south façade with wide overhangs and awnings.
- Specify the opaque portion of the building envelope with higher thermal integrity, and with lower probability of moisture condensation.
- Specify efficient lighting, with controls to take advantage of daylight.
- Because of the good envelope, and because of the efficient lighting, obtain lower peak loads. Primary heating/cooling equipment, fans, ducts and pipes are reduced.
- Provide a highly efficient HVAC system, using geothermal heat pumps.

- Provide ASHRAE standard 62 outside air rates.[36]

The DOE-2.1E analysis simulated the building using a 16-zone model to account for variations in function, schedules, and azimuth in the building. The DOE-2.1E analysis had the advantage of starting with a base-case scenario that was proven to be 34%-36% more energy-efficient than a similar, code-compliant design.

In addition to all of the energy efficient building designs that are being used, good indoor air quality (IAQ) is achieved through the use of a mechanical system that employs an air-to-air heat exchanger that recovers heat from exhaust air, and introduces a greater volume of outdoor air into the building. The indoor environment is also improved by using healthy building materials and finishes. Finally, the Center further reduces its environmental impact by incorporating stonework and exposed wood framing materials that are sustainably harvested on-site, as well as composting toilets.

In order to improve understanding and awareness of the surrounding ecosystem, the Center has installed a network of remote environmental monitoring stations in both terrestrial and aquatic environments. The monitoring sensors also include: the indoor environment, relative humidity (RH), power usage (kwh), water usage, indoor and outdoor air temperature, and the wind velocity. It is projected that all of the efficient strategies will "yield annual energy savings of between 43-49% in comparison to a code-compliant building; regardless of one's position on environmental issues, that's the kind of resource conservation you can bank on."[37]

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36 Energy Simulation of Black Rock Forest Center For Science and Education, Using the Computer Program DOE-2.1E, Steven Winter Associates, Inc., Feb. 28, 1998

37 'Whole Buildings' in a Black Rock Forest: Design Team Brings Passive Solar, Geothermal, & SIPs together Under One Roof, Steven Winter Associates, Inc., Press Release, April 9, 1999.

Chapter 3

COMPARISONS AND GRAPHS BASED ON DATA COLLECTED AT BLACK ROCK FOREST CENTER FOR SCIENCE AND EDUCATION

INTRODUCTION:

The following graphs have been constructed using data obtained from the monitoring stations at Black Rock Forest Center for Science and Education. These stations monitored the following variables at Black Rock Forest on an hourly basis, for two weeks:

- Average Outdoor Temperature (ʻF)
- Maximum Outdoor Temperature (ʻF)
- Minimum Outdoor Temperature (ʻF)
- Average Indoor Relative Humidity (RH)
- Maximum Indoor Relative Humidity (RH)
- Minimum Indoor Relative Humidity (RH)
- Power Usage (Kwh)
- Effluent
- Battery Volt

The indoor air temperature was calculated according to the energy simulation report of Black Rock Forest For Science and Education.[38] The indoor air temperature during the heating period (winter) was divided into two sections. *Section I* is made up of the offices, computer areas, labs, and meeting Room. *Section II* is made up of the living quarter.

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[38]Energy Simulation of Black Rock Forest Center For Science and Education, Using the Computer Program DOE-2.1E, Steven Winter Associates, Inc., Feb. 28, 1998, pg. 11.

Hours	*Section I* Temperature ('F)	*Section II* Temperature ('F)	Average Temperature ('F)
2400-600	65	68	66.5
600-700	65	72	68.5
700-800	72	72	72
800-1700	72	65	68.5
1700-1800	72	72	72
1800-2200	65	72	68.5
2200-2400	65	68	66.5 **Total Indoor Average: 68.9**

Table 5: Indoor Air Temperature at Black Rock Forest Center

According to the equation for the Theoretical Efficiency of a Heat Pump: Tlow/(Thigh-Tlow), the overall theoretical efficiency of the geothermal heat pump at Black Rock Forest is:

- T-low = 19.4 ' F (the average outdoor temperature) = 266.15K
- T-high = 68.9 'F (the average indoor temperature) = 293.65K

So, the overall theoretical efficiency = 266.15/(293.65-266.15)= 9.678.

Even though the graphs are more detailed, they show the same overall efficiencies.

PROCEDURE:

Using the data from the monitoring stations at Black Rock Forest Center for Science and Education, I compared and analyzed the following trends for one day, one week, and two weeks:

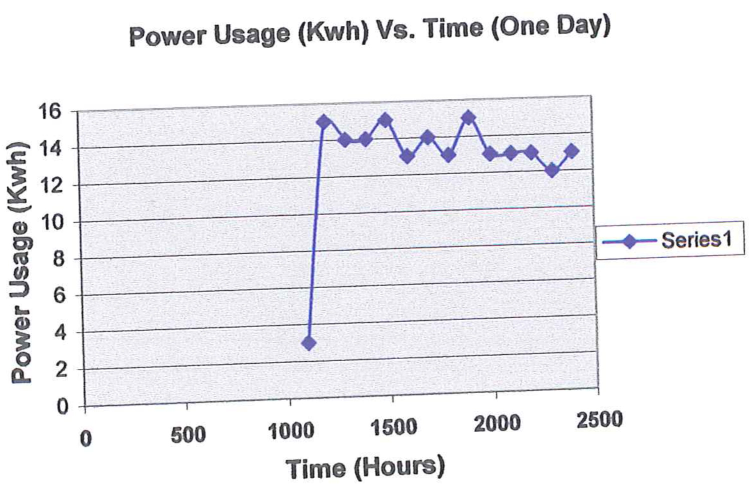
1) Power Usage Vs. Time (graphs 1a-1c)
2) Power Usage Vs. Theoretical Efficiency (graphs 2a-2c)
3) Power Usage Vs. Actual Efficiency (graphs 3a-3c)
4) Power Usage Vs. Average Temperature (graphs 4a-4c)
5) Power Usage Vs. Minimum Temperature (graphs 5a-5c)
6) Power Usage Vs. Maximum Temperature (graphs 6a-6c)

All of the graphs were made using Microsoft Excel.

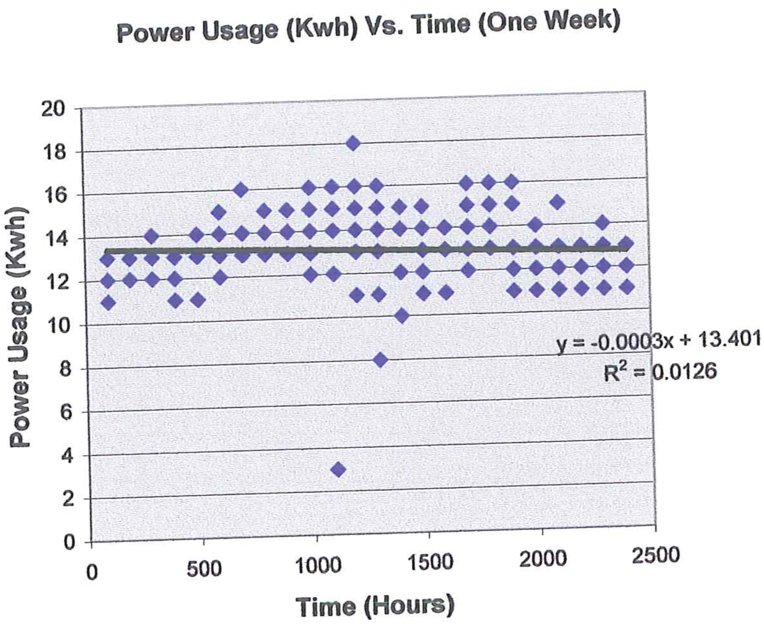
RESULTS ANALYSIS, AND DISCUSSION:

All of the graphs show trends that are consistent with the expected results. Graphs 1a-1c show the Power Usage Vs. Time for one day, one week, and two weeks. As these graphs show, there is not a very strong correlation between the time of day and the power usage. According to the graphs, power usage decreases as the day moves on. The correlation coefficient (r^2) is low, and decreases as the data increases. Power Usage is affected by many things including lights, computers, building occupancy, and outside temperature. All of these things fluctuate throughout the day, causing the power usage to fluctuate accordingly.

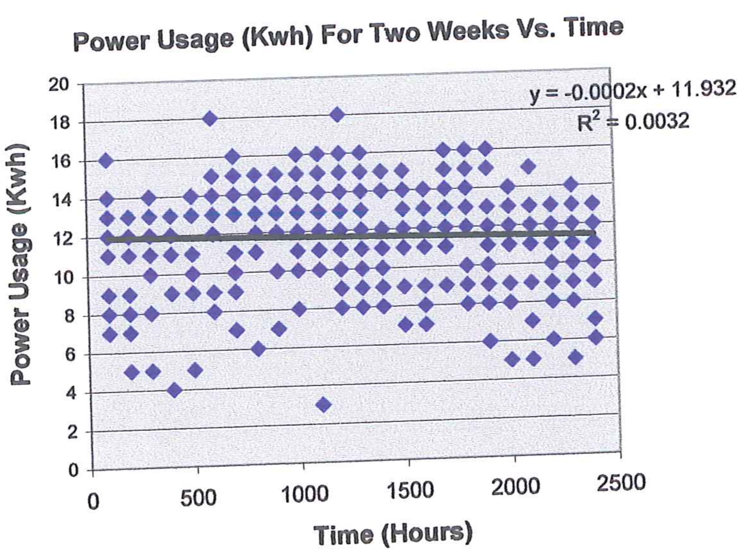
GRAPH 1A



GRAPH 1B:

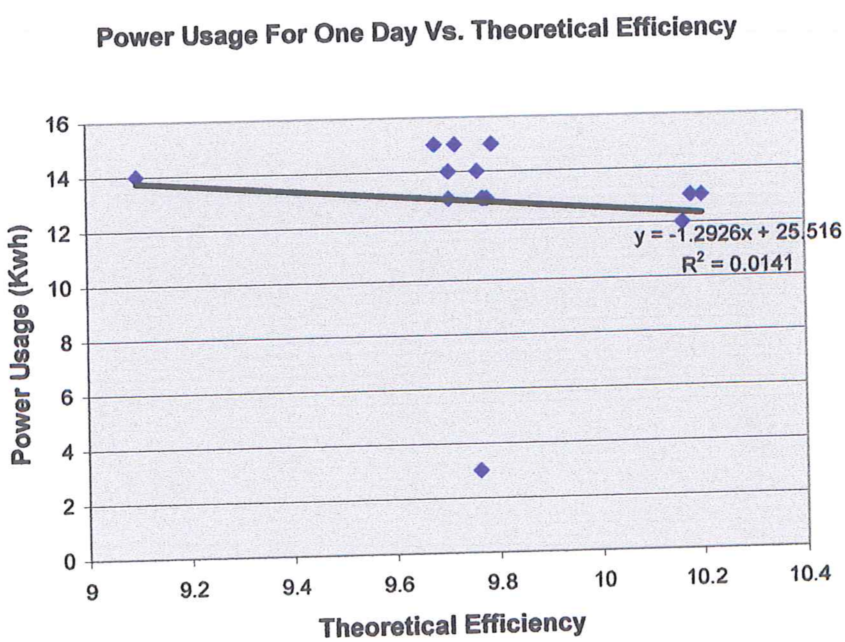


GRAPH 1C:

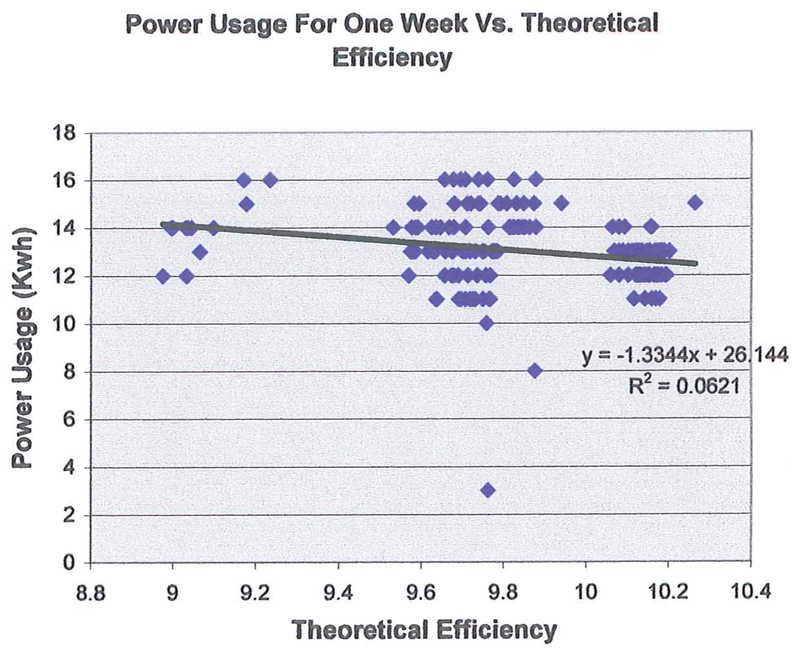


Graphs 2a-2c show the Power Usage Vs. Theoretical Efficiency. All three of these graphs show the expected results, namely, an inverse relationship between power usage and the theoretical efficiency. The theoretical efficiency of a heat pump is calculated by: Tlow/(Thigh-Tlow), where Tlow = the average outdoor temperatures for each hour, and Thigh = the average indoor temperatures. As the amount of data increases from one day to two weeks, the trends become stronger. This is reflected by an increasing R^2 coefficient, and an increasingly negative slope. (The negative slope represents the way that the power usage decreases as the theoretical efficiency increases.

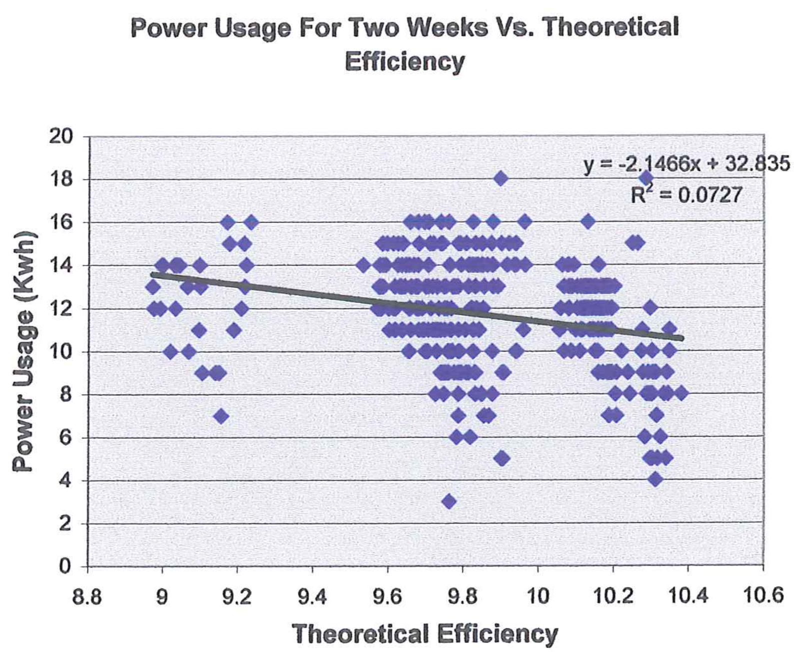
GRAPH 2A:



GRAPH 2B:

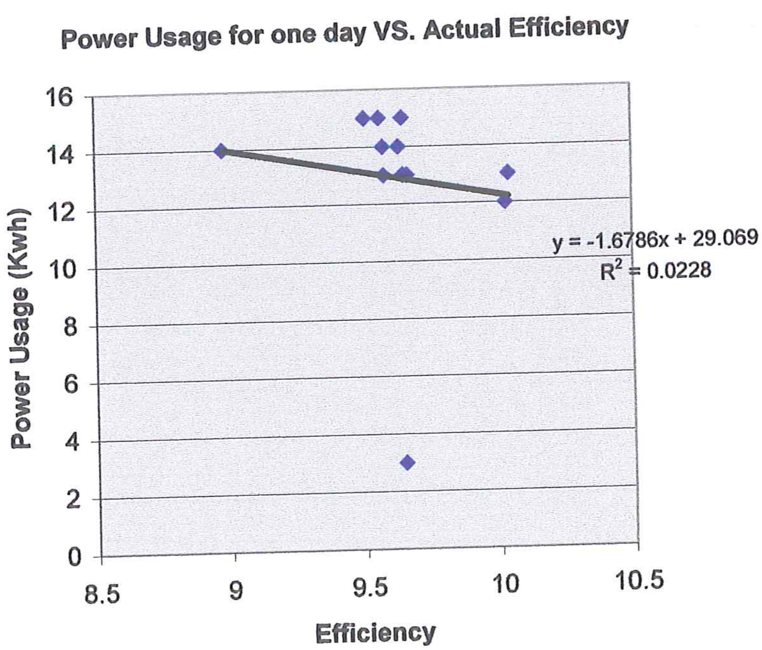


GRAPH 2C:

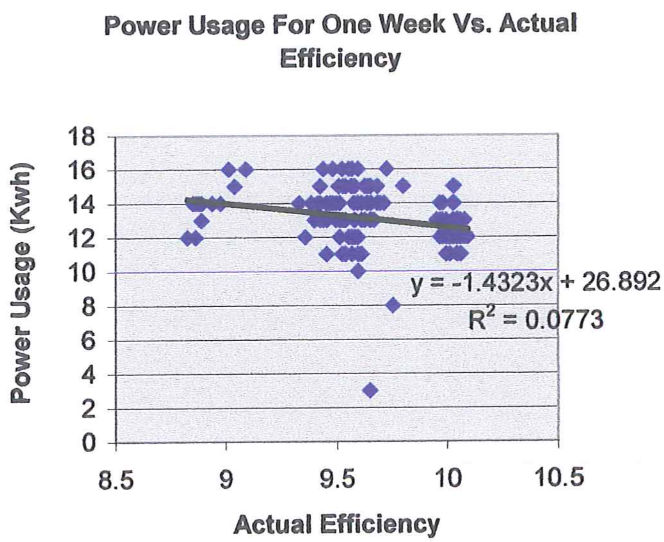


Graphs 3a-3c show the Power Usage Vs. Actual Efficiency. These graphs show the same trends as graphs 2a-2c. The actual efficiency is calculated by using the equation for the efficiency of a heat pump, where Tlow = minimum outside temperature, and the average inside temperature for Thigh. The theoretical efficiency is a little higher than the actual efficiency because the it is calculated using the average outdoor temperatures for Tlow, which include the maximum outdoor temperatures. This raises the outside temperatures, making the difference between outdoor and indoor temperature smaller. The heat pump works more efficiently when this difference is smaller.

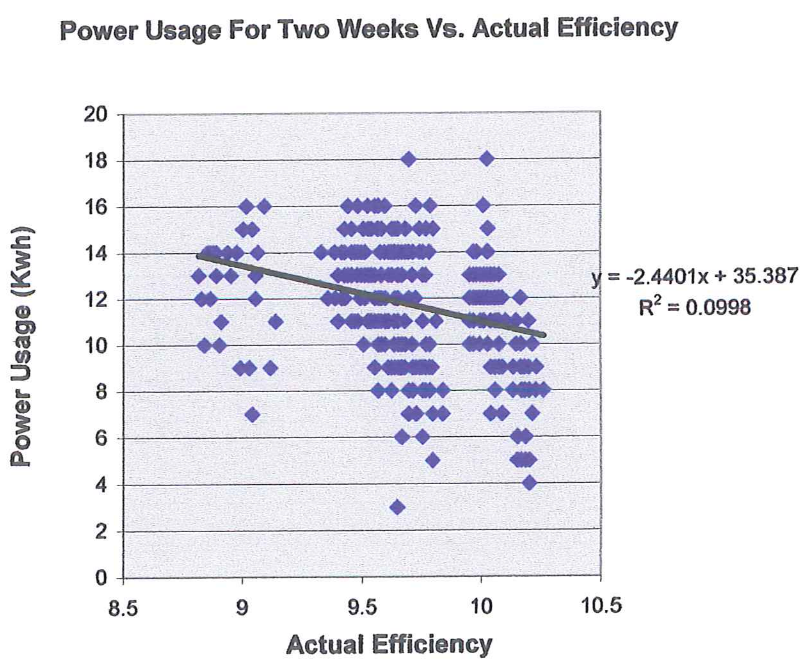
<u>GRAPH 3A:</u>



GRAPH 3B:

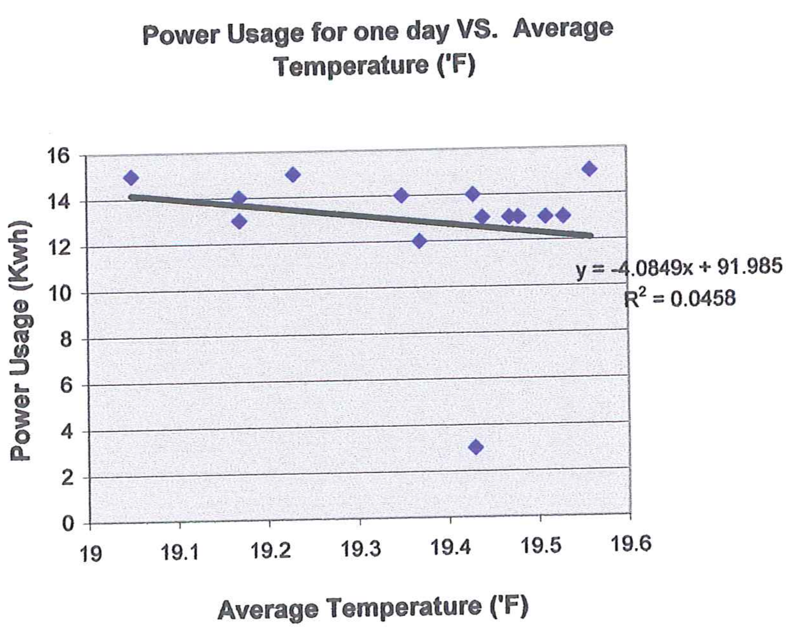


GRAPH 3C:



Graphs 4a-4c show the Power Usage Vs. Average Outdoor Temperature. These graphs plot the projected results, and show that as the average outdoor temperature increases, the power usage decreases. This happens because the difference between indoor and outdoor air decreases, enabling the heat pump to use less power (and work less hard) to warm the building. The inverse correlation between power usage and average outdoor temperature becomes stronger as time moves on, and more data is collected. Between one day to two weeks, the negative slope becomes sharper, and the R^2 coefficient increases from 0.0458 after one day, to 0.0874 after two weeks. The trendline in Graph 4b does not show expected or consistent trends, and we can only assume it is because there is not enough data, or there is some type of percent error.

GRAPH 4A:



boiler and cooling tower would cost roughly $14,000.00 for one year.[39] This is $8582.303 in savings per year. Over the 30-40 year expected lifetime of the geothermal heat pump, this savings comes to $257,469.09 - $343292.12!!!!!!!!!! This translates into a lot of untaxed money that Black Rock Forest can invest into the pursuit of knowledge and science education.

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[39] Energy Simulation of Black Rock Forest Center For Science and Education, Using the Computer Program DOE-2.1E, Steven Winter Associates, Inc., Feb. 28, 1998.

Chapter 4

CONCLUSION AND SUGGESTIONS FOR FURTHER RESEARCH

As is shown in this report, there are many incentives, both economic and environmental, to use a geothermal heat pump. In my mind, I think that the following statements regarding customer satisfaction speak for themselves:

According to *Marketing Exchange*, published by NRECA,

> Seventy-eight percent of the owners said the main advantage of the ground source heat pump is that it saves them money on their electric bills. Other advantages are: they don't have to run for hot water, it is maintenance free, and it saves electricity.
> Owners were asked to rate the efficiency of their ground source heat pump on a scale of one to ten. Ninety seven percent gave a rating of an eight or higher. Over one half of the owners gave the heat pump a perfect ten.
> The overall satisfaction level of the ground source heat pump is very high. On a scale of one to ten, 97% rated it at eight or above and 97% of the same number of owners said that they would buy a ground source heat pump again.
> "The satisfaction rating is the highest I have ever seen relative to an energy product," says Dr. Hein.
> Buyers were also asked to rate the ground source heat pump on a scale of one to ten in terms of comfort in summer and winter. Ninety-nine percent rated the heat pump's ability to provide summer comfort as an eight or above, and 73% of these rated it a perfect ten. The pump's ability to provide winter comfort received an 83% rating at eight or higher and 58% gave it a ten. These winter ratings of the ground source heat pump are higher than the air-source heat pump ratings reported in the July issue of *Marketing Exchange*.
> Ninety-nine percent of the owners said they would recommend a ground source heat pump to their friends and 84% said that they would allow their name to be used in a testimonial.[40]

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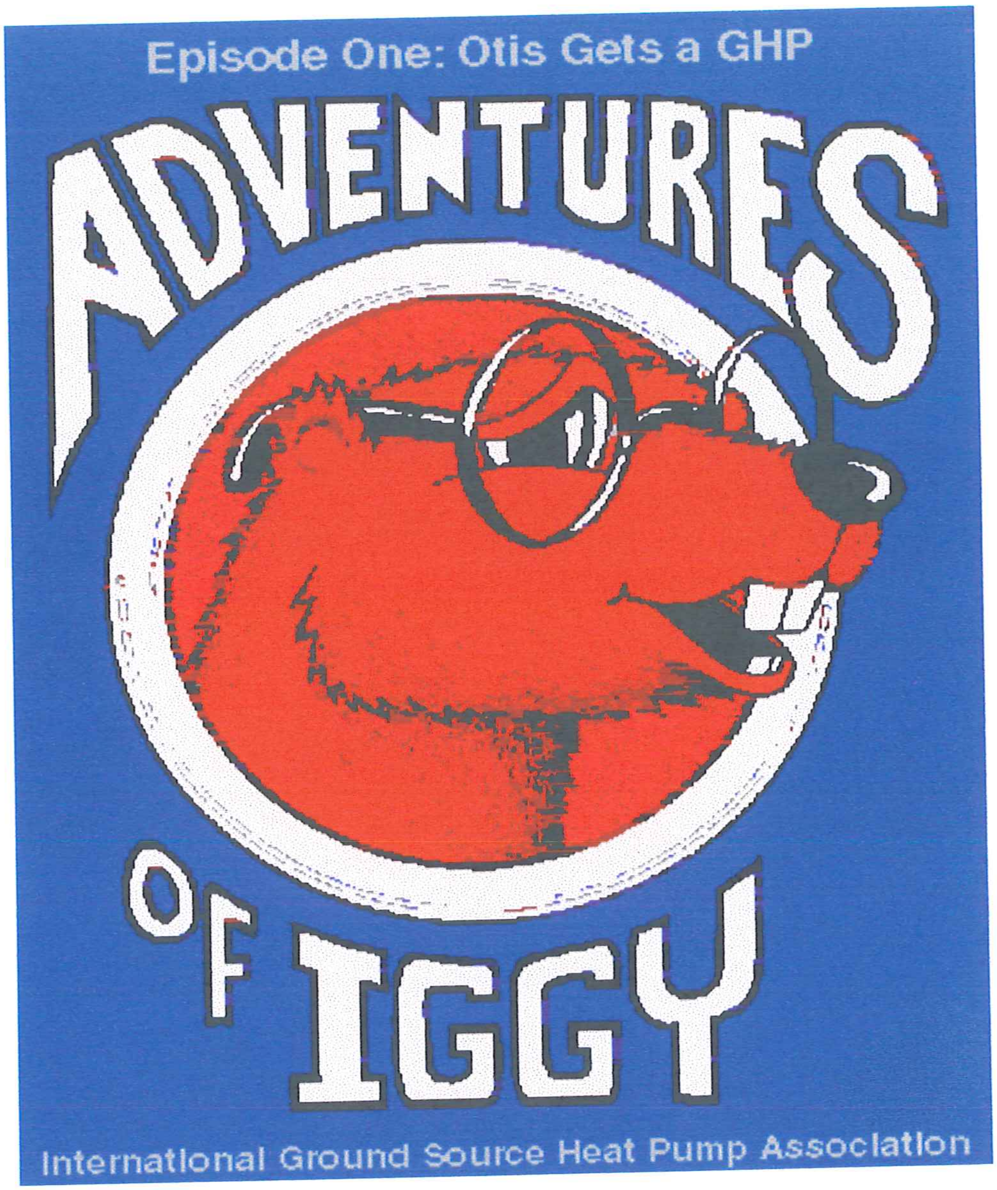
[40] "Ninety-Seven Percent of Ground Source Heat Pump Buyers Would Buy Again,," Marketing Exchange, (August 12, 1988. vol.2, #7), Published by NRECA, edited by AHP Systems.

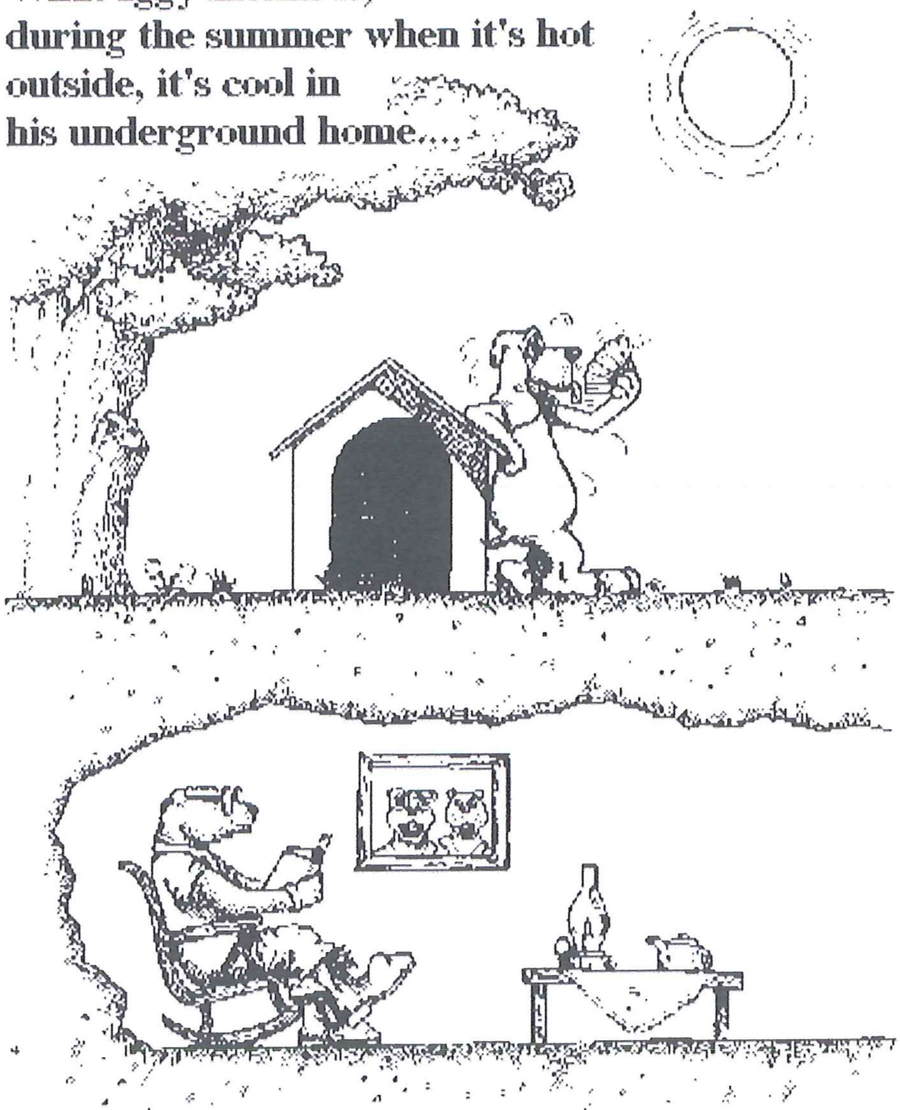
Further research should examine the cooling performance and efficiency of the Black Rock Forest geothermal heat pump. As more data is collected, the summer efficiency can be compared to the winter efficiency. It would also be interesting to explore the efficiency curves of summer as compared to winter: Which season remains efficient for a longer amount of time, and why. Finally, after a few years, the total savings in energy bills can be calculated- if the trends follow the aforementioned data, we can expect a very satisfying and rewarding result.

The following cartoon was created by the International Ground Source Heat Pump Association (IGSHPA).[41]

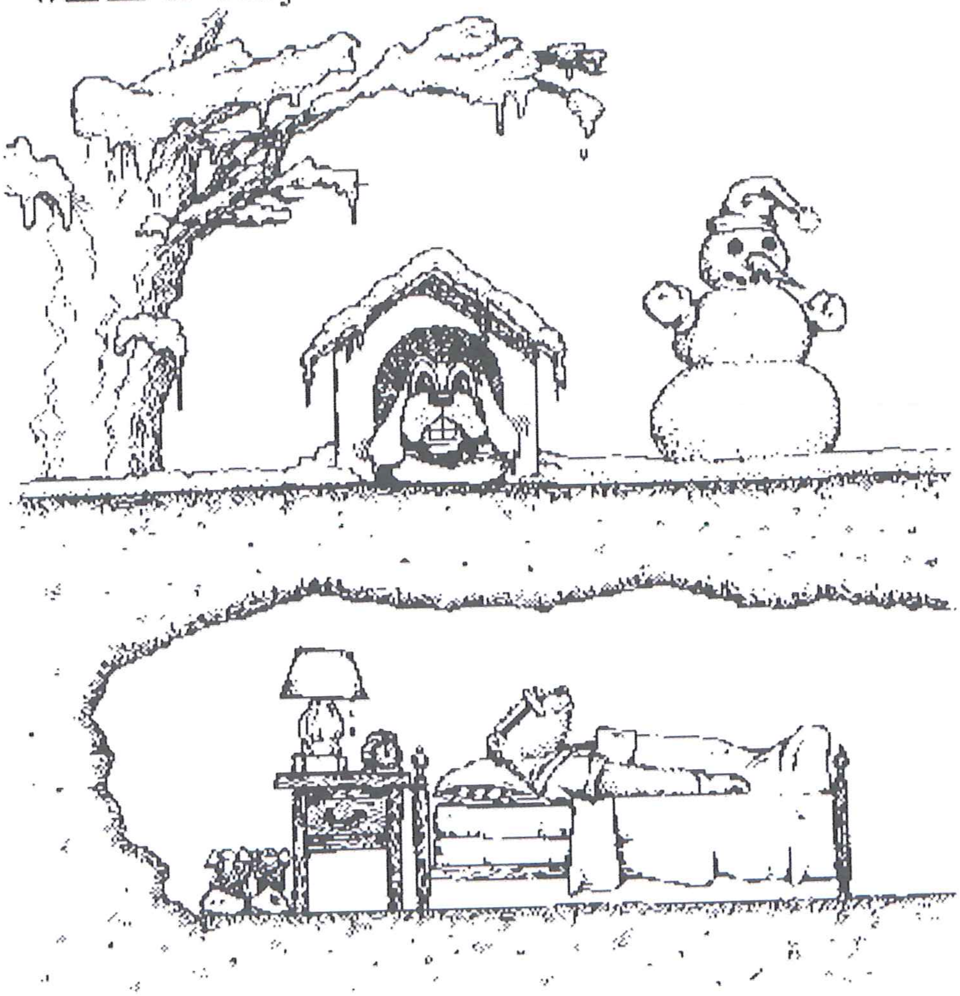


41 Adventures of Iggy, IGSHPA, Oklahoma State University, 22 December 1999, <http://www.igshpa.okstate.edu/Publications/Brochures/IGGY_ColorBK./Benefits.html.>.

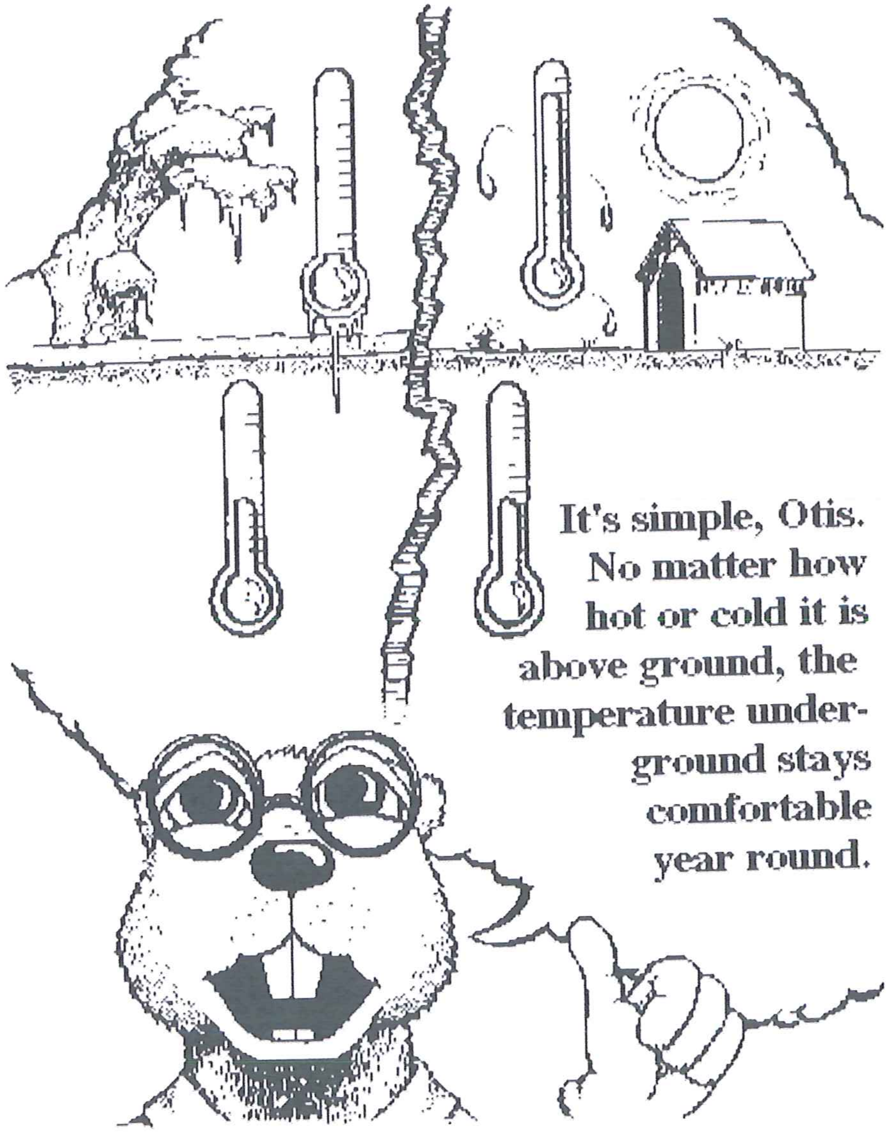
**What Iggy means is,
during the summer when it's hot
outside, it's cool in
his underground home....**

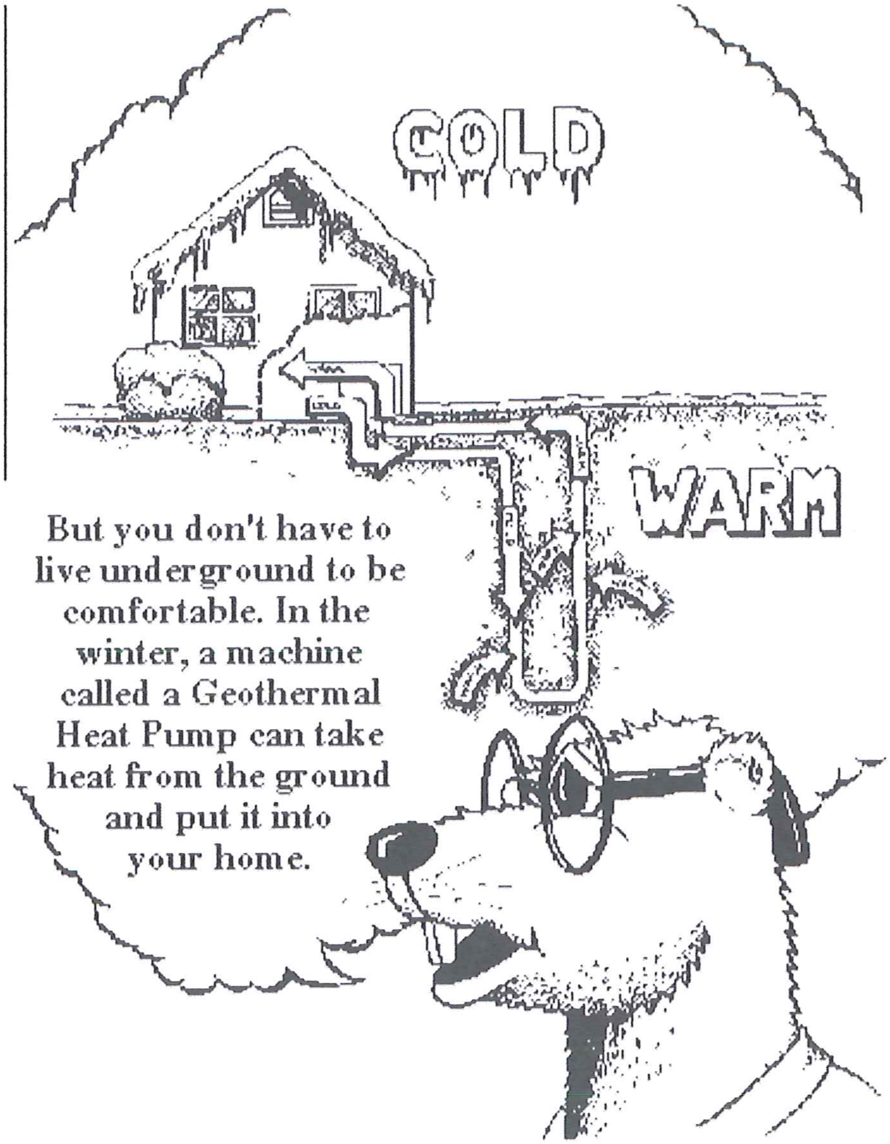


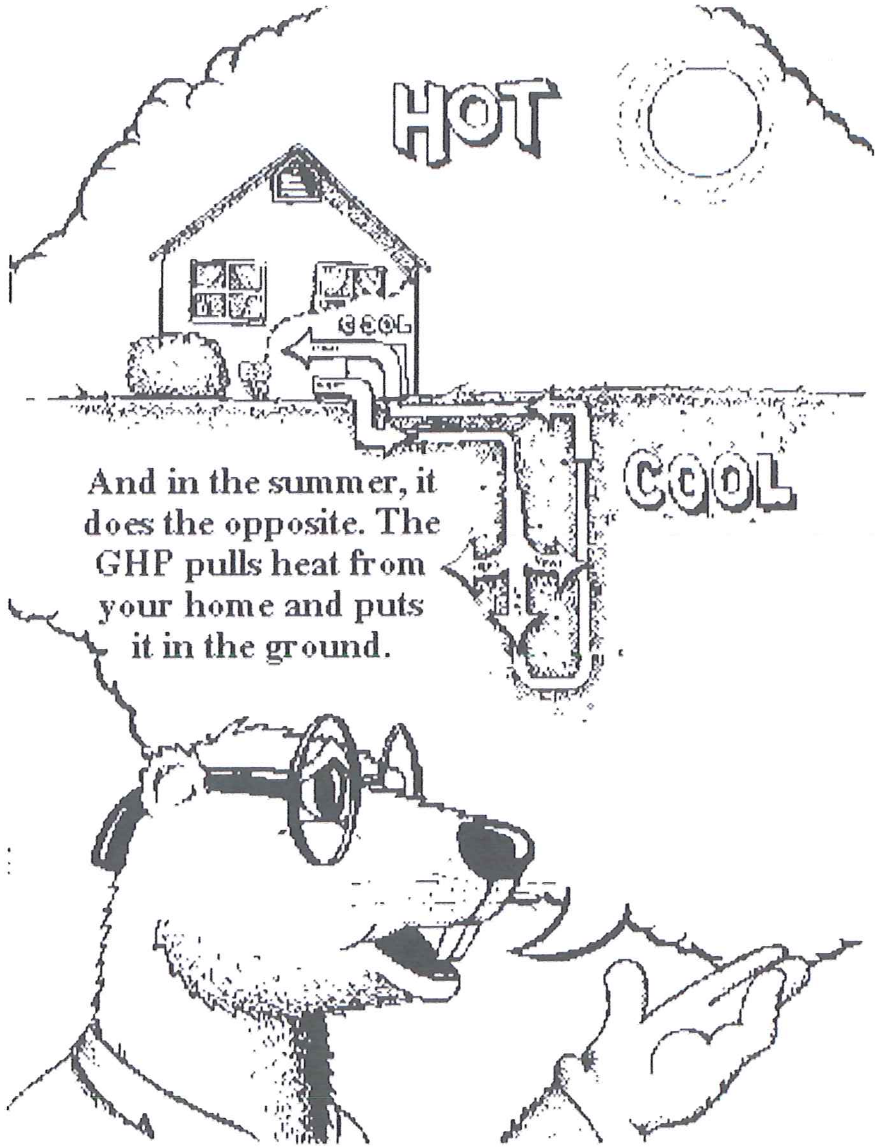
And in the winter when it gets very cold, Iggy's home stays warm & cozy.

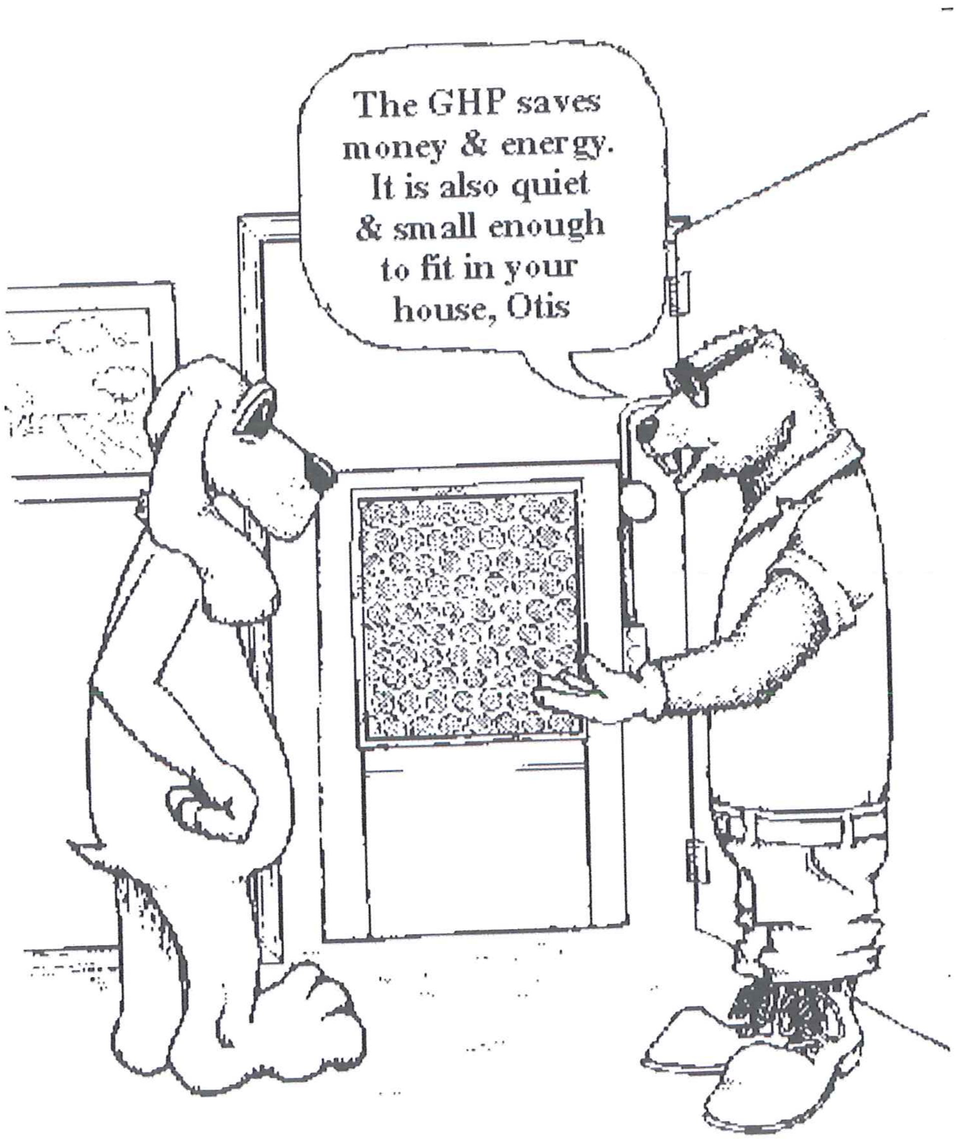


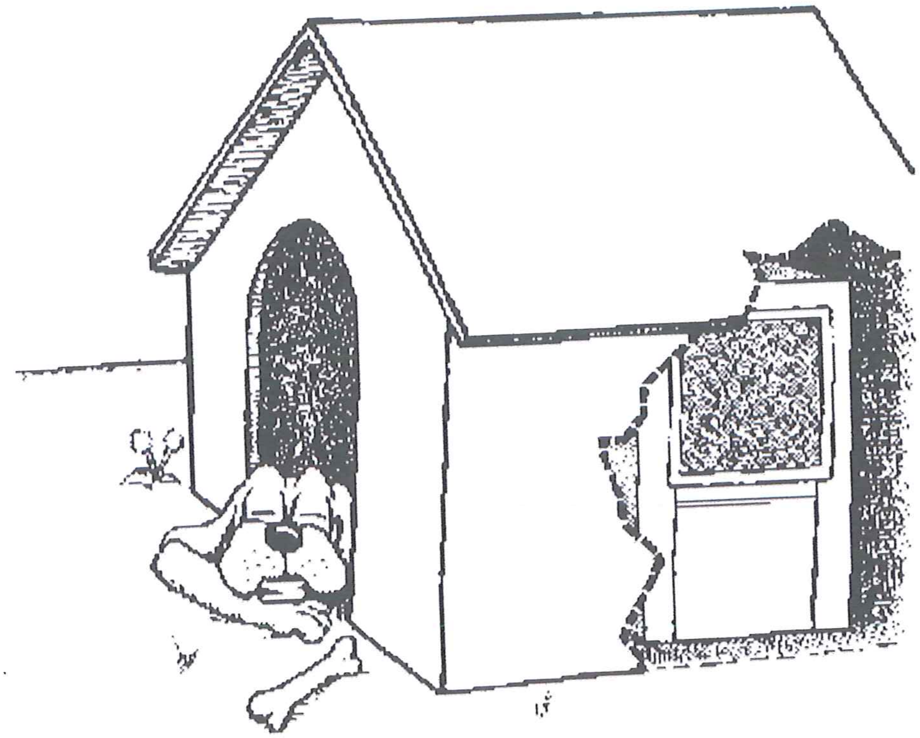

Iggy, why are you always so comfortable?


It's simple, Otis.
No matter how
hot or cold it is
above ground, the
temperature under-
ground stays
comfortable
year round.


COLD
WARM
But you don't have to live underground to be comfortable. In the winter, a machine called a Geothermal Heat Pump can take heat from the ground and put it into your home.


HOT
COOL
COOL
And in the summer, it does the opposite. The GHP pulls heat from your home and puts it in the ground.


The GHP saves money & energy. It is also quiet & small enough to fit in your house, Otis



With a GHP, Otis is now as comfortable as Iggy.

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