GEOTHERMAL HEAT PUMPS
- TRENDS AND COMPARISONS -

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Heat pumps are used where geothermal water or ground temperatures are only slightly above normal, generally 50 to 90°F. Conventional geothermal heating (and cooling) systems are not economically efficient at these temperatures. Heat pumps, at these temperatures, can provide space heating and cooling, and with a desuperheater, domestic hot water. Two basic heat pump systems are available, air-source and water- or ground-source.

Water- and ground-coupled heat pumps, referred to as geothermal heat pumps (GHP), have several advantages over air-source heat pumps. These are: (1) they consume about 33% less annual energy, (2) they tap the earth or groundwater, a more stable energy source than air, (3) they do not require supplemental heat during extreme high or low outside temperatures, (4) they use less refrigerant (freon), and (5) they have a simpler design and consequently less maintenance.

The main disadvantage is the higher initial capital cost, being about 33% more expensive than air-source units. This is due to the extra expense and effort to burying heat exchangers in the earth or providing a well for the energy source. However, once installed, the annual cost is less over the life of the system, resulting in a net savings. The savings is due to the coefficient of performance (COP) averaging around 3 for GHP as compared to 2 for air-source heat pumps.

Types of Geothermal Heat Pump Systems

Two major types exist: earth-coupled or water-source. The earth-coupled uses a buried earth coil with circulating fluid in a closed loop of horizontal or vertical pipes to transfer thermal energy to and from the earth. The water-source uses a well or an open pond to provide an energy source or sink. Earth-coupled systems have been used in northern Europe for many years, but were not used on a commercial scale in the U.S. until 1980. Earth coupling is used where insufficient well water is available; where the quality of well water is a problem; where drilling and casing of wells are expensive, or where disposal of well water is restricted.

In the horizontal mode of the earth-coupled system, pipes are buried in trenches spaced a minimum of 5 feet apart and from 4 to 6 feet deep. This allows for minimum thermal interference between pipes; however, this system is affected by solar radiation. Solar radiation will affect the earth to a depth of about 30 feet, causing a cycling of soil temperatures, that lags in time and decreases with depth due to the insulating properties of the soil (Figure 1); however, the temperature is much more stable than for air-source units. Moist soil will have greater temperature swings than dry soil. The loops can be placed in a double layer as shown in Figure 2. Vertical installation (Figure 3) of the coils are used where land space is limited or trenching would disturb the surface landscape, and drilling costs are reasonable. Holes are drilled approximately 150 feet deep and 15 to 20 feet apart.

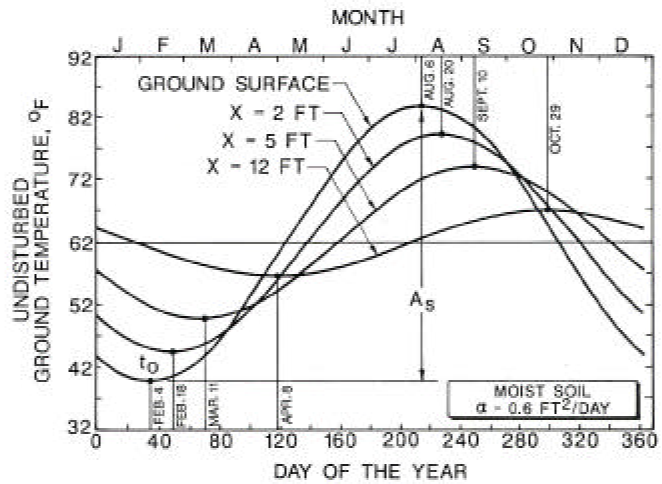

Figure 1. **Annual soil temperature variation, Stillwater, OK (Source: Oklahoma State University).**

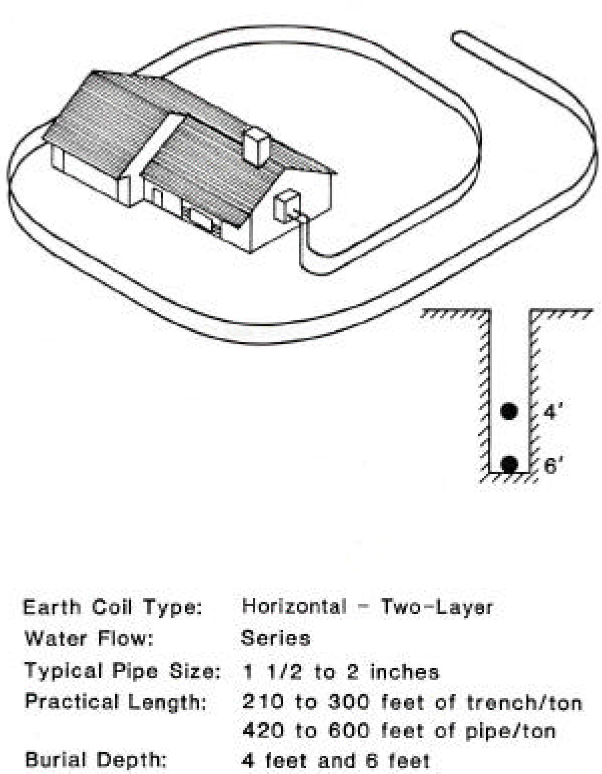

Figure 2. **Two-pipe horizontal ground heat exchanger (Source: Oklahoma State University).**

Computer programs have been developed (Reference 1) to calculate the length of horizontal earth coils for heating and cooling. Polyethylene pipes are the most popular in use, and along with socket-fusion joining, are usually guaranteed for over 50 years.

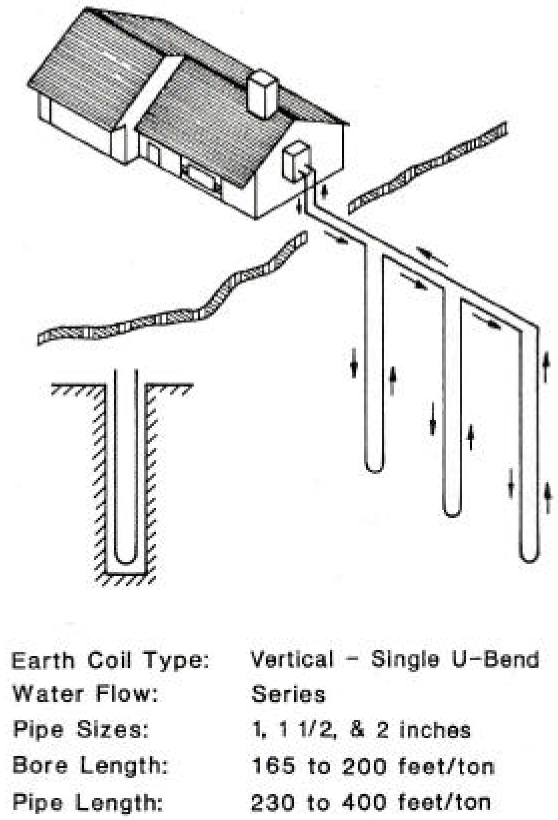

Figure 3. Series vertical ground heat exchanger (Source: Oklahoma State University).

Whereas, horizontal loops are affected by solar radiation, rain and wind; the vertical loops are controlled by the mean-annual temperature of the area and the geothermal gradient and thus, have a more stable temperature environment.

Water wells are usually used where one is already available, such as for domestic water supply. Normally, a minimum diameter of 6 inches and a production of about 3 gallons per minute per ton of heat pump capacity is required. Three tons, a typical residential load, requires about 9 gallons per minute. The 6-inch diameter well casing is required to place the pump and return line (Figure 4). The fluid can either be returned to the well by the return line, placed in an injection well, or disposed on the surface such as irrigation. Pipes have also been anchored to the bottom of surface ponds (minimum depth of 6 feet); however, the heating and cooling capacities are affected by solar radiation and other surface weather factors similar to the horizontal loops. Installation is cheaper and heat transfer is more efficient; however, ponds do not maintain a constant temperature as wells do and the pipes are more vulnerable to accidental damage.

The operation of the heat pump unit is the same for air-source and ground-source configuration. The main difference is that the air-source requires an outside unit (accumulator and fan) which may frost up in cold weather, requires frequent defrosting. They also require a backup heating source (electric or gas) when outside temperatures are too low for efficient operation. The operation and cycle in both heating and cooling mode of the heat pump are shown in Figures 5 and 6 (see Reference 4).

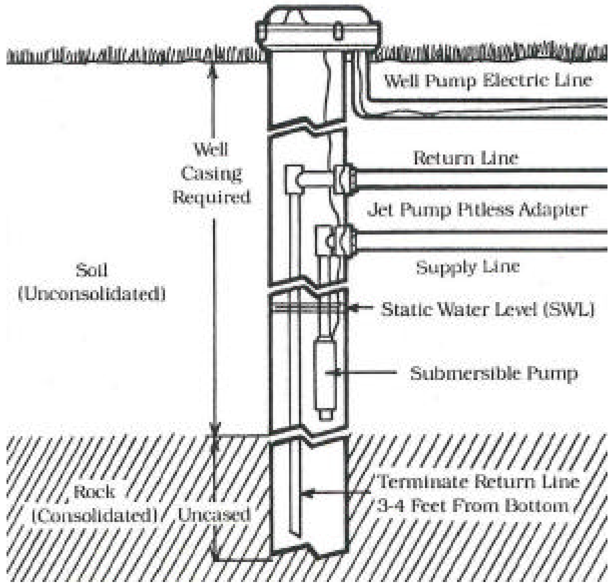

Figure 4. **Cross-section view of geothermal well (Source: Water Source Heat Pump Book).**

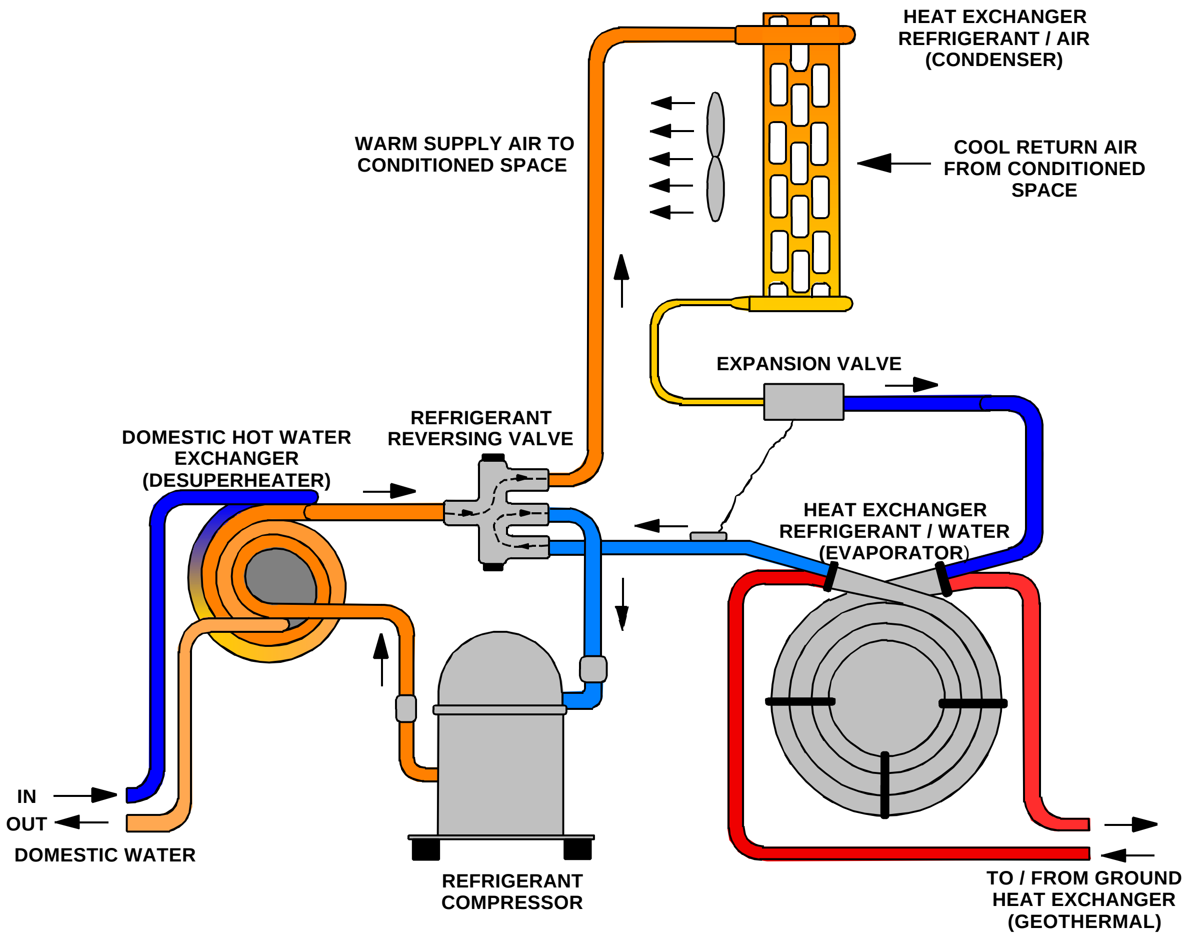

Figure 5. **Heating cycle (Source: Oklahoma State University).**

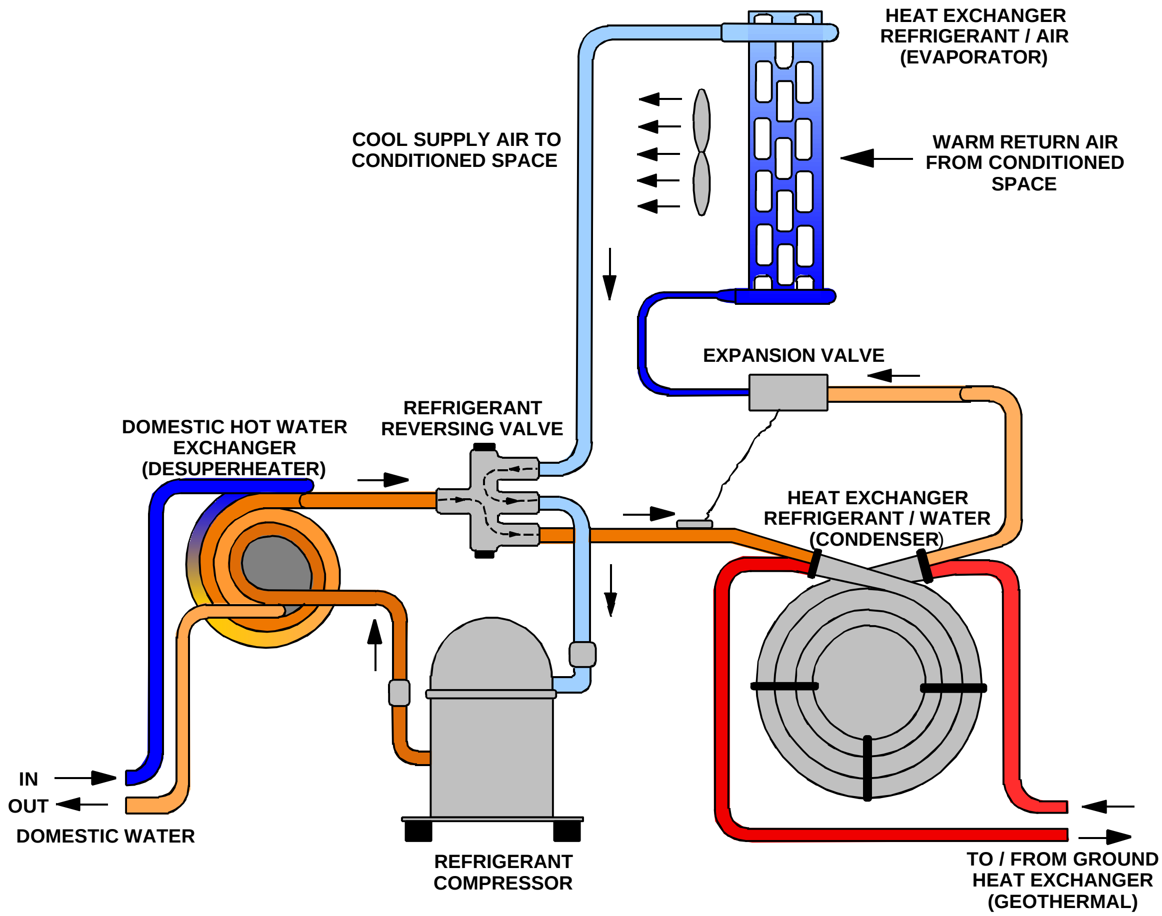

Figure 6. Cooling cycle (Source: Oklahoma State University).

Heat Pump Growth Potential

The Electric Power Research Institute (EPRI) and industry sources (Reference 4) estimate that 800,000 heat pump units (of all kinds) are presently installed annually, with sales growth of 25 to 40% annually. Of these, 25,000 per year are geothermal installations. By 2010, geothermal units will have captured 15% of the heat pump market. Presently, there are around 100,000 geothermal units installed in the U.S.

Since 1986, Canadian geothermal heat pump growth exceeds 50% and by 1990, the Executive Director of the Canadian Ground-Source Heat Pump Association expects the growth to exceed 100% annually. Geothermal heat pumps are ideally suited to Canada's climate and there are plans to retrofit air-source heat pumps which often operate on electric resistance heating much of the winter. Ontario, with a population of 11 million, has the potential to save 5,000 to 8,000 MW of electricity by 2010.

Depending upon incentives provided by utilities, state and federal governments, such as tax credits, installations subsides, etc., the total increase of geothermal heat pump installations will be between 10% (a 7-fold increase) and 18% (a 27-fold increase) over the next 20 years as summarized in the following tables:

Table 1. Conservative Case Scenario - 10% Growth

Year	Installation Rate/yr	Total Installed	Geothermal Energy Supplied In 10^9 Btu/yr*
1990	13,300	110,000	5,660
1995	13,400	177,000	9,100
2000	21,800	286,000	14,700
2005	34,800	460,000	23,700
2010	56,000	740,000	38,100

Table 2. Optimistic Case Scenario - 18% Growth Average (25% initially and dropping to 10%)

Year	Installation Rate/yr	Total Installed	Geothermal Energy Supplied In 10^9 Btu/yr*
1990	13,300	110,000	5,660
1995	55,000	385,000	20,000
2000	110,000	990,000	50,000
2005	165,000	1,820,000	93,400
2010	220,000	2,920,000	150,000

* Based on data presented in Reference 4.

The above growth scenarios are shown graphically in Figure 7.

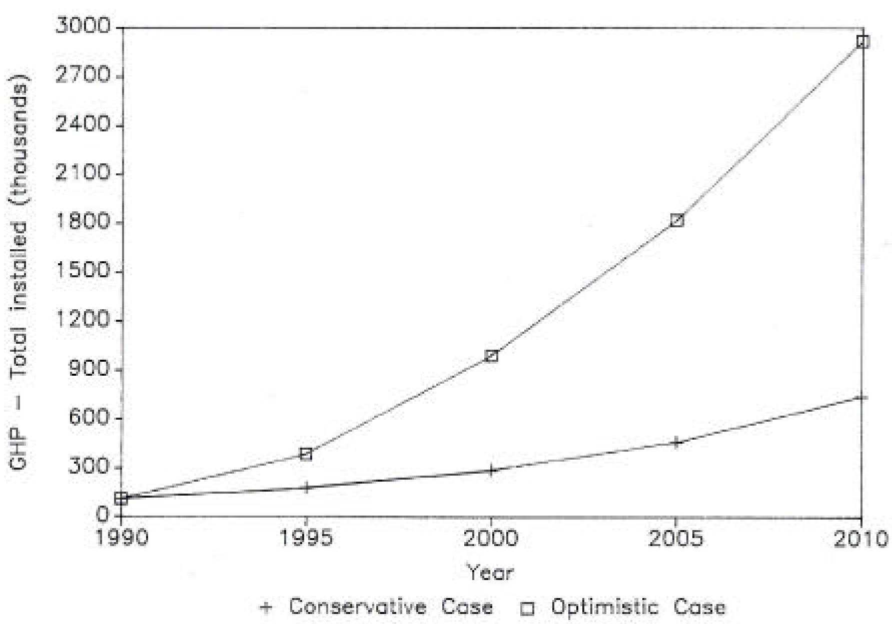

Figure 7. Growth scenarios for geothermal heat pumps.

As an example of incentives for geothermal heat pump installations, mainly to overcome the initial capital investment, the Public Service Company of Indiana (PSI) will pay residential developers the added cost of a geothermal heat pump over air-source heat pumps (the horizontal or vertical piping loop cost). To reduce the initial cost, PSI "mass produces" the installation of the geothermal heat pump by installing the system when the subdivision is under construction. This cuts the increment cost by about 50%. PSI considers this a good investment as it reduces the peak load, improves the load curve by adding winter demand, and reduces the need for costly new power plants. This program is being considered by other utilities throughout the nation.

Market penetration of geothermal heat pumps can be accelerated dramatically, if utilities have a profit motive for cost-effective conservation investments. One industry representative predicts that if the geothermal heat pump's first cost was equal to the air-source heat pump, their sales would soar to 400,000 annually, 50% of today's heat pump market. Assuming an increasing share of utilities promote geothermal heat pumps as capacity is required, the market share of geothermal heat pumps may reach 5 to 10% of the housing market by 2010, similar to the air-source heat pump market penetration over the past 15 years. The overall energy savings is estimated to reach 0.1 quad/yr (3,000 MW) by 1995, and over 0.6 quad/yr (20,000 MW) by 2010 (Sources: USDOE).

Cost Comparison Between Geothermal Heat Pumps and Conventional Heating/Cooling Methods

Four cities, representing different climatic regions of the United States, were selected for cost comparison between heat pumps and conventional-fueled systems. A typical northern community (Columbus, OH) and a typical southern community (Montgomery, AL) were initially selected, and then two extreme heating and cooling loads were also investigated for comparisons (Bismark, ND and Orlando, FL).

The comparisons are based on fall 1989 energy prices which are:

1. Electricity:

Orlando	\$0.075/kWh
Montgomery	\$0.070/kWh
Columbus	\$0.068/kWh
Bismark	\$0.067/kWh

2. #2 Fuel Oil (140,000 Btu/gal)

Orlando	\$1.09/gal
Montgomery	\$0.85/gal (est.)
Columbus	\$0.89/gal
Bismark	\$0.76/gal

3. Natural Gas (100,000 Btu/CCF)

Orlando	\$0.50/CCF
Montgomery	\$0.55/CCF
Columbus	\$0.51/CCF
Bismark	\$0.45/CCF

4. Propane (LPG)(38,000 Btu/gal)

Orlando	\$1.22/gal
Montgomery	\$0.835/gal
Columbus	\$0.91/gal
Bismark	\$0.47/gal

In comparison, the fuel prices in Klamath Falls are:

Electricity	\$0.045/kWh
Fuel Oil	\$0.839/gal
Natural Gas	\$0.478/CCF
Propane	\$1.469/gal

It should be noted that fuel oil is limited in southern states, since the heating load is low, and that propane is generally only used in outlying regions of urban areas.

The annual cost of using the various fuels in the four locations for heating, cooling and domestic hot water are:

Table 3. Orlando, Florida

	Earth HP	Water HP	Air HP	Elect.	Oil	Natural Gas	Propane
Heating	\$ 90	\$ 90	\$ 100	\$ 160	\$ 115	\$ 65	\$ 175
Cooling	975	995	1005	1005	1005	1005	1005
Hot Water	205	210	285	285	135	90	240
Ops. Cost/Yr	1270	1295	1390	1450	1255	1160	1420
Cap. Cost/Yr	820 (940)*	585	530	530	605	555	555
Total Cost/Yr	2090 (2210)*	1880	1920	1980	1860	1715	1975

* The first figure is for a horizontal pipe system and the one in ( ) is for a vertical pipe system.

Table 4. Montgomery, Alabama

	Earth HP	Water HP	Air HP	Elect.	Oil	Natural Gas	Propane
Heating	$ 185	$ 190	$ 285	$ 425	$ 255	$ 205	$ 340
Cooling	560	570	575	575	575	575	575
Hot Water	220	225	300	300	120	110	185
Ops. Cost/Yr	965	985	1160	1300	950	890	1100
Cap. Cost/Yr	820 (940)*	585	530	530	605	555	555
Total Cost/Yr	1785 (1905)*	1570	1690	1830	1555	1445	1655

* The first figure is for a horizontal pipe system and the one in ( ) is for a vertical pipe system.

Table 5. Columbus, Ohio

	Earth HP	Water HP	Air HP	Elect.	Oil	Natural Gas	Propane
Heating	$ 490	$ 500	$ 685	$ 990	$ 695	$ 485	$ 965
Cooling	150	150	215	215	215	215	215
Hot Water	270	275	365	365	155	125	250
Ops. Cost/Yr	910	925	1265	1570	1065	725	1430
Cap. Cost/Yr	820 (940)*	585	530	530	605	555	555
Total Cost/Yr	1730 (1850)*	1510	1795	2100	1670	1280	1985

* The first figure is for a horizontal pipe system and the one in ( ) is for a vertical pipe system.

Table 6. Bismark, North Dakota

	Earth HP	Water HP	Air HP	Elect.	Oil	Natural Gas	Propane
Heating	$ 880	$ 895	$1055	$1585	$ 960	$ 695	$ 805
Cooling	110	110	110	110	110	110	110
Hot Water	305	315	420	420	150	130	150
Ops. Cost/Yr	1295	1320	1585	2115	1220	935	1065
Cap. Cost/Yr	820 (940)*	585	530	530	605	555	555
Total Cost/Yr	2115 (2235)*	1905	2115	2645	1825	1490	1620

* The first figure is for a horizontal pipe system and the one in ( ) is for a vertical pipe system.

Discussion

The above figures are based on a typical well insulated home of 1,800 sq ft requiring 438 Btu/hr°F heating requirement and with a family of four using 70 gals/day of domestic hot water. Capitol costs are amortized at 10% for 20 years. Heating efficiencies are calculated at 70% for oil, 80% for natural gas and propane. No operation and maintenance costs are included.

The calculations and data are based on information provided in the "Directory of Certified Applied Air-Conditioning Products" (Ground Water-Source Heat Pump section) and the "Directory of Certified Unitary Air-Source Heat Pumps" produced by the Air-Conditioning and Refrigeration Institute, Arlington, WA (1989) and from the "1989 ASHRAE Handbook - Fundamentals" I-P Editional, Atlanta, GA. The details of the calculations can be obtained by contacting the Geo-Heat Center.

As the heating load increases, the cost of using an electric furnace for heating increases in comparison to heat pumps. Oil and natural gas prices are extremely low due to the current depressed cost of these products, which may increase considerably in the future. The annual cost shown above does not consider price increases in the future, which most likely will be greater for oil and natural gas than for electricity.

If subsidies are provided to pay the cost of the horizontal or vertical pipe loop system in earth-coupled heat pump systems, such as instituted by the Public Service Company of Indiana, then the "Total Cost/Yr" for each of the above "Earth HP" would be $1855, $1550, $1495 and $1880 respectively for each of the locations. This reduces the annual cost below that of all alternate systems except natural gas (except for Bismark). Columbus is probably the city that best represents an average cost comparison for the U.S.

References

1. Dexheimer, R. Donald, 1985. Water-Source Heat Pump Handbook. National Water Well Association, Worthington, OH.

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3. Lund, John W., 1988. "Geothermal Heat Pump Utilization in the United States," Geo-Heat Center Quarterly Bulletin, Vol. 11, No. 1 (Summer), Klamath Falls, OR.

4. Oklahoma State University, Division of Engineering Technology, 1988. Closed-Loop/Ground-Source Heat Pump System - Installation Guide, International Ground Source Heat Pump Association, Stillwater, OK.