GEOTHERMAL HEAT PUMP PERFORMANCE

Tonya L. Boyd and Paul J. Lienau

Geo-Heat Center
Oregon Institute of Technology
Klamath Falls, OR

ABSTRACT

Geothermal heat pump systems are a promising new energy technology that has shown rapid increase in usage over the past ten years in the United States. These systems offer substantial benefits to customers and utilities in energy (kWh) and demand (kW) savings. The purpose of this study was to determine what existing monitored data was available mainly from electric utilities on heat pump performance, energy savings and demand reduction for residential, school, and commercial building applications. Information was developed on the status of electric utility marketing programs, barriers to market penetration, incentive programs, and benefits.

INTRODUCTION

The Department of Energy (DOE) and the Environmental Protection Agency (EPA) are rapidly expanding their involvement in programs to promote increased use of both renewable-energy resources and energy-efficient technology. Federal implementation of the Clean Air Act Amendments of 1990 and the Energy Policy Act of 1992, and other regulations still under development are a result of an increasing worldwide environmental consciousness. Furthermore, the environmental and efficiency aspects of energy production and use are expected to remain top-priority items in President Clinton's administration. Geothermal heat pumps (GHPs) can help meet the challenge by increasing our energy efficiency, with resulting benefits to utilities in better load management, to customers in lower utility bills, and to society in a cleaner environment (Pratsch, 1992).

UTILITY ISSUES

Electric utilities are the ultimate market target for GHPs, especially utilities that are already committed to demand-side management (DSM). Recommendations must be consistent with prevailing energy policies and supported by data. The data must show that the resource, and technology is available, reliable, plus cost competitive with other options. Concerns of utilities considering GHP technology as a DSM option include:

- Amount of demand and energy savings,
- First cost of ground loop and wells,
- Effect of ground-loop temperature increase for summer and long-term operation, especially for commercial applications,
- Utility rebates and other incentives, and
- Infrastructure availability of heat pump dealers and loop installation contractors.

MONITORING PARAMETERS

The object of this study was to compare as many types of like case studies, with monitored data, taken from as many sources as possible throughout the United. States. The monitoring strategy for GHPs can be classified into:

<u>Basic Parameters</u>:

- Heat pump demand (kW) and energy (kWh),
- Supply and return ground-loop temperatures, and
- Flow in ground loop, a one-time measurement.

<u>Comprehensive Parameters</u>:

- Ground-loop pump kW and kWh,
- Fan kW and kWh,
- Air flow,
- Air supply and return temperatures, and
- Space and outside temperatures.

Due to the complex variations that affect a system's performance, it is difficult to exactly compare two different applications. The goal of this study was to compare as many case studies of similar data as possible, to establish a pattern rather than attempt to remove the variables for an exact comparison.

PERFORMANCE

The energy performance of a GHP system can be influenced by three primary factors: the heat pump machine, the circulating pump or well pump, and the ground-coupling or groundwater characteristics.

The heat pump is the largest energy consumer in the system. Its performance is a function of two things: the rated efficiency of the machine and the water temperature produced by the ground-coupling (either in heating or cooling mode).The most important strategy in assembling an efficient system is to start with an efficient heat pump. It is difficult and expensive to enlarge a ground-coupling to improve the performance of an inefficient heat pump.

Water-source heat pumps are currently rated under one of three standards by the American Refrigeration Institute (ARI). These standards are ARI-320, ARI-325 and ARI-330. The standard intended for ground-coupled systems is ARI-330 entitled "Ground Source Closed Loop Heat Pump Equipment." Under the standard, ratings for cooling EER and heating COP are published. It's important to consider that these are single-point ratings rather than seasonal values as in the case of air-source equipment. Cooling EER values are based on an inlet water temperature of 77ºF (25ºC). Heating COP values are based on a heating inlet water temperature of 32ºF (0ºC). The current ARI directory contains equipment with EER ratings of less than 10 to a high of 18.6. COP values range from 2.8 to 3.6. Evidently, there is a wide range of equipment performance at the standard rating conditions. Considering these values, it is evident that the performance of the equipment can vary by as much as 100% according to the quality of the heat pump purchased.

In recent years, there has been a substantial increase in the efficiency of GHP equipment. Based on performance reported in the ARI directory for 1987 and 1994, the increase in EER ranges from 26 to 56 percent, and in COP from 35 to 50 percent depending on the entering-water temperatures. Figures 1 and 2 show this increase in performance for a typical machine based on average values of EER and COP as a function of entering-water temperature.

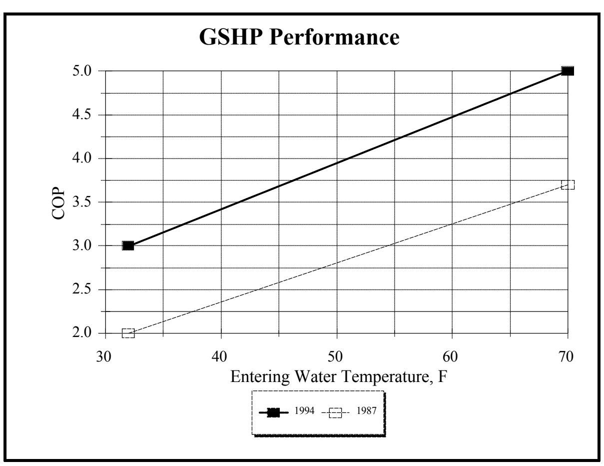

Figure 1. GSHP performance improvement from 1987 to 1994 for heating mode.

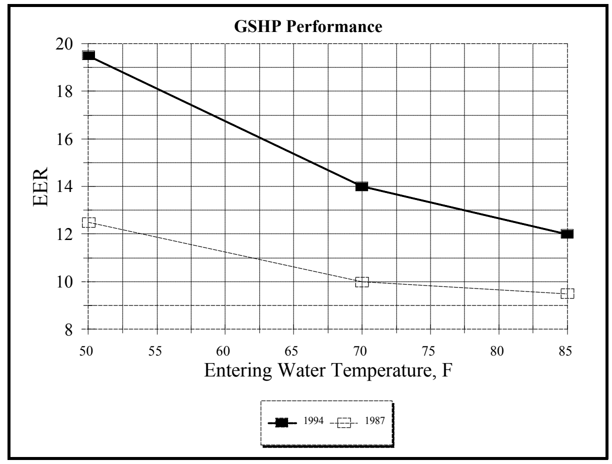

Figure 2. GSHP performance improvement from 1987 to 1994 for cooling mode.

In summary, it is necessary when evaluating a ground-coupled system to consider the efficiency of the machine, the adequacy of the ground-coupling, and the nature of the pumping design to fully understand the efficiency of the system.

CASE STUDIES

In order to verify the performance of geothermal heat pumps, information from 256 case studies was collected from primarily utilities throughout the United States. They include: 184 residential, 26 school, and 46 commercial systems. These case studies were compiled into a database. The database contains 65 data fields which includes: installation date, location, ground system configuration, data monitored, capacity, and energy/economics.

Residential

Households use about 1/5 of the primary energy consumed in the U.S. (including the energy required to produce electricity and deliver it to final users). Space heating accounts for the largest single share of primary energy use in the residential sector for the nation as a whole.

Residential electric space heating can potentially help both summer and winter peaking utilities achieve several load- shape modification objectives. A utility may make strategic conservation and peak reduction investments by promoting efficient heat pumps to replace resistance heaters (or less efficient heat pumps).

To determine the potential of geothermal heat pump (GHP) systems to satisfy these objectives, existing monitored data and other information was collected from electric utilities, rural electric cooperatives, manufacturers, engineers, universities, and other sources.

Of the 184 case studies, only 128 GHP and 46 conventional systems were monitored. Conventional systems could include: electric resistance heating, air-source heat pumps, natural gas furnace with electric air conditioner (AC), oil furnace with electric AC, and others. These conventional systems were compared to GHP systems for energy savings patterns, power reduction for electric resistance (heating only), operating costs, etc. Figures 3 and 4 show patterns of dollar savings of residential GHP systems compared to air-source heat pumps and natural gas furnace. The mean-annual dollar savings of GHP compared to air-source heat pumps is 31%, and the natural gas furnace is 18%. Due to the high first cost of GHP systems, mainly because of the additional incremental costs of the ground loop, economics is an important issue. Even though the percent-dollar savings may appear attractive because of relatively low-annual operating costs of conventional systems, it is difficult to recover the additional incremental cost of the GHP system. The economics section addresses this problem.

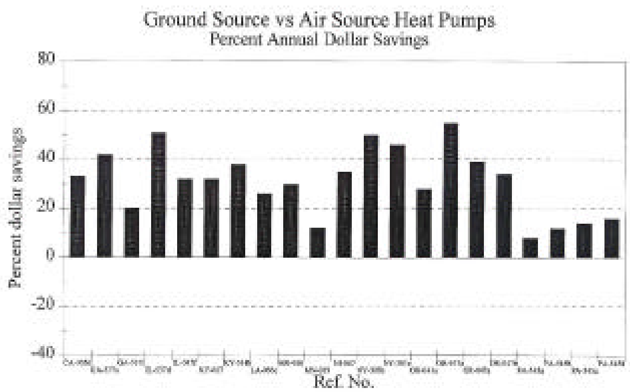

Figure 3. Residential GSHP annual dollar savings compared to air-source heat pumps in percent.

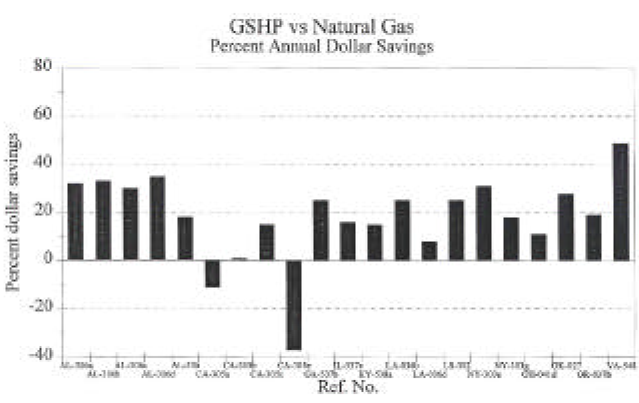

Figure 4. Residential GSHP annual dollar savings compared to natural gas furnace with electric AC in percent.

Peaking performance improvements of GHP systems can be evaluated as a coincident peak that occurs at the time of the utility peak. A non-coincident peak occurs at the time of the greatest difference between the GHP system load and the competing systems load.

Figure 5 show winter non-coincident peak demand reduction of GHP systems compared to single-zone electric heating systems. For these 13 systems, the range was 5.3 to 10.4 kW with a mean of 7.2.

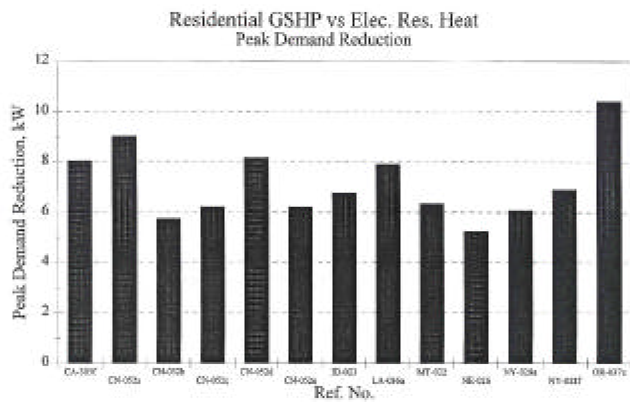

Figure 5. Residential GHP peak demand reduction compared to single-zone electric resistance heating systems.

Schools

Most school districts in the nation make every effort to keep expenses at a minimum, while still providing top quality education and a comfortable environment. Conserving energy dollars is one of the most direct and effective ways of reducing expenses. Annual energy savings were reported for six schools and a total of five case studies reported annual dollar savings out of the 26 gathered. The potential for energy savings in schools throughout the United States is demonstrated by two case studies described in Table 1. The first is a middle school in Wahpeton, North Dakota, employing a ground-coupled system. The second is a high school located at Junction City, Oregon, employing a groundwater system.

Table 1. School Ground-Coupled and Groundwater GSHP Systems.

School:	Wahpeton, ND	Junction City, OR
Installed date:	1988	1988
System:	286 boreholes (150 ft)	Production/injection wells
Application:	Middle school (57,400 ft^2)	High school (55,300 ft^2)
Design condition:	8564 HDD[a], -25°F	4793 HDD, 17°F
Capacity:	220-tons	101-tons
Energy:	678,000 kWh/yr	193,133 kWh/yr
Installed cost:	$418,000	$265,000
Savings/yr:	106,800 therms of gas[b]	35,506 therms of gas

a. Heating degree day
b. Calculated

In the case of the North Dakota school, there is three times the energy savings over the Oregon school due primarily to the fact of being located in a much colder climate. Benefits reported for using GHPs in schools include: addition of mechanical cooling, improved control--being able to condition a very small area without having to condition the entire school, and simplicity of maintenance and repair. In southern climates, the elimination of cooling towers, outdoor equipment, mechanical rooms and ductwork were added benefits.

Commercial

Case studies (46) documented for GHPs in commercial buildings ranged in capacity from 30 to 4700 tons. These systems employed ground-coupled well fields of up to 370 boreholes for an 850-ton system, to 3 wells for a 4700-ton groundwater system. The average annual energy savings for GHP systems ranged from 40 to 72%, and dollar savings ranged from 31 to 56% as can be seen in Table 2.

Table 2. Commercial GSHP Annual Savings.

Conventional System	Mean Annual Savings (%)			
	Number	Energy	Number	Dollars
Elec. res. heat/AC	6	59%	5	56%
Air-source heat pump	3	40%	3	37%
Natural gas	4	69%	4	49%
Fuel oil	6	72%	7	31%

The savings attributable to the use of GHP systems in commercial buildings vary over a wide range, in addition to such parameters as climate, GHP system type, soil conditions, equipment efficiency, sizing and other issues which influence GHP applications. Unique to commercial buildings are building use, internal heat gains, and more complex rate structures.

In addition to the internal, occupancy and process loads, commercial building energy use can also be influenced by the shape and orientation of the structure, quantity of ventilation air, presence or absence of heat recovery, and a host of other parameters. By influencing loads, these factors also affect savings to be achieved by more efficient HVAC systems.

Clearly given all the potential influences upon commercial building energy use, prediction of savings to be achieved with a GHP system becomes a very site-specific endeavor.

ECONOMICS

The economics of GHP systems are represented by the simple payback reported in the case studies. There were 27 residential, 5 school, and 17 commercial systems that reported simple paybacks as shown in Table 3.

Table 3. Geothermal Heat Pump Economics.

		Simple Payback	
	Number	Range (yr)	Mean (yr)
Residential	27	1.4 to 24.1	6.8
Schools	5	5.0 to 14.0	7.0
Commercial	17	1.3 to 4.7	2.8

Residential GHP system simple paybacks were compared to various conventional systems as shown in Figure 6. The range for residential simple paybacks was 1.4 to 24.1 and a mean of 6.8. As shown in Figure 6, the simple paybacks for when GHP replaced natural gas furnaces ranged from 4.2 to 24.1 with four of the nine cases reporting simple paybacks greater than 10 years.

Simple paybacks for schools were reported in only 5 out of 26 case studies. Therefore, this is not a good statistical representation of economics for using GHPs in schools. Commercial building case studies reported simple paybacks for 17 out of 46 GHP systems. The range was 1.3 to 4.7 with a mean of 2.8. All but four of the simple paybacks represent buildings located in northern climates.

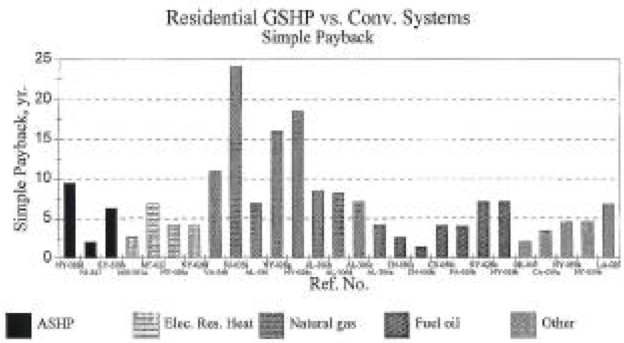

Figure 6. Residential GHP simple paybacks compared with conventional energy systems.

Caution should be used in arriving at economical conclusions for any of the three groups presented in this paper. In part, this is due to the many variables associated with GHP systems and a variety of economic analysis methods used in the case studies. When considering a GHP system for either new or retrofit situations, it is imperative that a deliberate economic analysis be performed.

UTILITY PROGRAMS

Demand-side planning is increasingly becoming an accepted part of the planning process of U.S. electric utilities. Stimulated by the rising costs of constructing new power plants, increasing environmental concerns over emissions from fossil fuel plants, and resulting regulatory pressures, electric utilities are looking more to the demand side as a source for meeting energy and load requirements.

Geothermal heat pumps are one of many technologies that utilities are considering or implementing for demand-side management (DSM), especially aimed at improving the efficiency with which customers use electricity. The results of DSM programs aimed at energy efficiency provide two benefits: they save energy and reduce peak demands. Information was developed on the status of DSM programs for about 60 utilities and rural electric cooperatives including: marketing programs, barriers to market penetration, incentive programs, number of GHP units installed in service area, and the benefits to the utility. The most common marketing programs were newspaper and radio/TV advertisement, test and demonstrations of GHP system performance, education programs, and home shows.

The primary barrier to marketing GHP systems according to a majority of the utilities is the incremental cost of installing the ground loop. Other deterrents to the implementation of GHPs cited by utilities are: natural gas is inexpensive; lack of manufacturers, suppliers, dealers and loop installers; and customer resistance to heat pump technology.

Utilities have designed a number of incentive packages to encourage the installation of GHPs. In most cases, these incentives include cash rebates (average $60/kW), low-cost financing, discounted energy rates, lease/purchase programs and in a few cases, ground loop installations.

CONCLUSIONS

Geothermal heat pumps are an effective means to reduce both consumer energy consumption and electric peak loads. To date, the geothermal heat pump industry has been primarily residential and has been most successful in areas characterized by winter peaking utilities, moderate electric rates and moderate-to-severe winter heating requirements.

The two items that influenced geothermal heat pump performance, in one locality apart from others, are ground characteristics and climate. Software is currently available from both manufacturers and independent sources to predict performance of residential systems under specific conditions, given input on ground characteristics and climate. Current and up-to-date information on the geothermal heat pump designs, especially used in commercial sector, are not easily found. There is a need to further document information on the operating experience with this technology and report on success and/or failure encountered at various locations in the United States.

ACKNOWLEDGEMENT

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REFERENCES

Pratsch, L. W., 1992. "Geothermal Heat Pumps Benefit the Consumer, Utility, and Nation", Geo-Heat Center Quarterly Bulletin, Vol. 14, No. 1, pp. 1-6.