RESIDENTIAL EARTH-COUPLED AND GROUNDWATER HEAT PUMP DEMONSTRATIONS AND FOLLOW UP TECHNOLOGY TRANSFER

Gary D. Allhusen
New York State Energy Research and Development Authority

ABSTRACT

A field demonstration of state-of-the-art residential earth-coupled heat pump systems was conducted in Upstate New York. The monitored data indicates that properly sized, installed and maintained packaged liquid-to-air earth-coupled heat pump units with any water heating option will achieve a seasonal performance factor (SPF) range of 2.5 to 3.0. Horizontal and vertical earth loops were found to perform almost identically when horizontal systems are sized at 450 trench ft/ton and vertical systems are sized at 180 vertical ft/ton, where tonnage refers to the nominal capacity of the heat pump. It was found that properly sized earth-coupled heat pumps run continuously on winter peak days at a demand of approximately 1.1 kW/ton. Although some backup electric resistance cycles in as needed at night and in the early morning, only 1.1 kW/ton occurs at the typical 7 p.m. system peak of Niagara Mohawk Power Corporation.

Concurrent with the earth-coupled demonstration, fifteen groundwater heat pumps, installed in single-family residences throughout New York State, were monitored from the fall of 1982 to the spring of 1984. Two forms of SPF were calculated from the data collected during the heating season: unit SPF and system SPF. The energy supplied to the house was the same for both calculations, but the unit SPF did not account for well pump energy whereas the system SPF did. Unit SPF's ranged from 2.1 to 3.3. Including well pump energy in the calculation, system SPF's ranged from 1.9 to 3.0. A system SPF of 2.75 can be expected for a properly installed and maintained groundwater heat pump. In the cooling mode, energy savings were achieved by adding an additional heat exchanger and bypassing the compressor for direct cooling. Dehumidification was sacrificed in this mode. Utilizing the compresser for cooling, system EER's ranged from 5.1 to 14.0.

Upon completion of the two heat pump projects, a technology transfer project was undertaken to disseminate the results of the demonstrations. "A Technical Guide to Ground-Source Heat Pumps" was published summarizing the results of the demonstrations. The audience for the technical guide was New York State's heating, ventilating and air conditioning industry. As a follow up to the technical guide, a ground-source heat pump seminar was produced. The seminar package consisted of research presentations made by each of the principal investigators in the demonstration projects combined with descriptions of a number of field applications presented by ground-source heat industry representatives. A brochure was also published which provides a description of the ground-source heat pump technology.

RESIDENTIAL EARTH-COUPLED AND GROUNDWATER HEAT PUMP DEMONSTRATIONS AND FOLLOW UP TECHNOLOGY TRANSFER

Gary D. Allhusen
New York State Energy Research and Development Authority

INTRODUCTION

The ground-source heat pump program at the New York State Energy Research and Development Authority (Energy Authority) is focused on adapting state-of-the-art water-source heat pump technology for application in New York State. Two demonstration projects, cofunded in part by the Energy Authority under the ground-source heat pump program, were completed in late 1984. One project entitled "Residential Earth-Coupled Heat Pump Demonstration" monitored a total of nine closed-loop heat pump systems, located throughout upstate New York, for space heating, cooling and domestic water heating performance values. A second project entitled "Ground Water Heat Pump Evaluation" monitored fifteen open-loop heat pump systems located throughout the entire State for space heating and cooling performance values. In light of the successful completion of the two demonstration projects, a major technology transfer effort was undertaken to disseminate the results of the demonstrations and aid in developing an infrastructure of high volume, low cost earth loop installers within New York State. The following presents a description of both the earth-coupled and groundwater heat pump demonstration projects as well as an overview of the Energy Authority's technology transfer efforts to date.

ENERGY SOURCES

There are two energy sources used in ground-source heat pump installations: groundwater aquifers and earth-coupled loops.

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, discharged into a stream or pond, or used for other purposes. A groundwater heat pump system is also called an open-loop system.

Earth-coupled heat pump systems use earth loops, or pipes buried in the ground. There are two basic loop configurations: horizontal and vertical. In the horizontal system, an antifreeze solution circulates through a ground coil buried in a 2.5' to 6' deep trench to absorb heat from the earth (trench depth depends on climate and operating characteristics of the heat pump). Horizontal loops can also be laid on the bottom of a pond or lake, utilizing the heat stored in the water. After passing through the ground coil, the antifreeze enters a liquid-to-refrigerant heat exchanger in the heat pump where it exchanges heat with the refrigerant. The vertical earth loop system is designed to accomplish the same result as the ground coil system, but can be installed in vertical holes, thus minimizing site area requirements. An earth-coupled heat pump system is referred to as a closed-loop system.

Groundwater Supply and Discharge

The groundwater heat pump incorporates an open-loop water system, using groundwater as the low-temperature heat source for heating operations. Typically, a well is required, but spring water or water from a lake with an appropriate operating temperature range has also been used. The source must be adequate enough to provide between 1.5 and 3 gallons of water per minute per ton of heat pump capacity for operation.

Groundwater is usually supplied to the heat pump by means of a drilled well with a submersible pump system. The pump must be submerged enough to remain 15-20 feet below the lowest well-water level. A filtering screen should be placed in a section of the indoor piping before the heat pump in order to limit the number of particles that pass through the liquid-to-refrigerant heat exchanger. Once the groundwater passes through the heat pump, an acceptable means of discharging the thermally altered water must be provided. Many areas have codes and regulations regarding the discharge of groundwater and these guidelines must be followed.

Earth Loop Configurations

Earth loops can be laid horizontally into trenches or inserted vertically into drilled holes. Since both have similar performance, the overriding consideration is the installed cost.

The basic horizontal configuration uses one pipe per trench, and can be installed in series or in parallel. To lower cost, several multiple configurations that require less trench length are available.

A second configuration uses two pipes per trench, and can also be installed in series or in parallel. A third horizontal configuration uses four pipes per trench. This configuration must be installed in parallel to avoid excessive pressure drop and the necessity for larger pipe diameters.

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 the one that can be installed for the least cost at a particular site. When sized properly, all configurations should result in a similar system performance.

HEATING PERFORMANCE

A meaningful indicator of system performance is the seasonal performance factor (SPF). The SPF is a defined as the ratio between all energy supplied to the house during a heating season and all energy consumed by the heat pump system during the season. The SPF includes all real inefficiencies of a heat pump system, such as cycling of the heat pump as well as pumping power and power consumed by the electric resistance heaters. In the earth-coupled heat pump demonstration, SPF values ranged from a high of 3.0 to a low of 1.5. In the groundwater heat pump evaluation, SPF values ranged from a high of 3.0 to a low of 1.9. For comparison, SPF values for air-source heat pumps average 1.6 in northern climates (Blake, 1980). Listed below are SPF values for the individual sites monitored under each project.

Site	Earth-Coupled Systems SPF/SEER	Groundwater Systems SPF/SEER
1	2.9/11.7	2.4/9.6
2	2.9/10.5	2.1/7.7
3	3.0/13.5	2.5/14.0
4	2.5/8.0	2.3/---
5	2.1/---	3.0/13.3
6	2.9/11.3	2.2/---
7	2.5/7.8	2.2/---
8	1.8/5.2	2.2/8.4
9	1.5/6.1	2.4/---
10		2.3/8.1
11		2.1/5.6
12		2.1/7.6
13		2.6/---
14		2.4/8.9
15		1.9/---

--- No cooling data

Figure 1. Heating and cooling performance data.

The ranges of SPF values were dependent upon many factors. Installation, system design, operation all impacted heat pump performance. For example, the groundwater system with a low SPF value of 1.9 was at a site which had a deep well (over 600 feet deep) with only marginal yield. Well pump energy was relatively high and the unit was operated with a groundwater recirculation loop which lowered the system's inlet temperature. These factors, plus less than optimal flow rate through the heat pump contributed to the low system SPF (Rackliffe, 1985).

COOLING PERFORMANCE

The steady-state efficiency of a heat pump in the cooling mode is measured in terms of its energy efficiency ratio (EER). The EER is defined as the ratio of the rate of energy removed from the house to the rate of energy consumed by the heat pump. The system EER integrated over an entire cooling season is called the <u>seasonal energy efficiency ratio</u> (SEER). In the earth-coupled heat pump demonstration, SEER values ranged from 13.5 to 5.2. In the groundwater heat pump evaluation, SEER values ranged from 14.0 to 5.6. For comparison, SEER values for central air conditioners range from 9.0 to 6.0. Figure 1 also lists SEER values for the individual sites monitored under each project.

Groundwater heat pumps can provide cooling in two ways. By reversing the heat pump cycle, the compressor can be used to extract heat from indoors and reject it to the water loop. Compressor cooling requires significantly more energy than direct water-to-air cooling. With direct water-to-air cooling, an additional water-to-air heat exchanger is installed into the water loop and the heat pump is bypassed. The relatively constant 50°F water temperature can provide sufficient cooling all summer long. One advantage of using the heat pump for cooling, however, is that it provides better dehumidifcation than direct groundwater cooling. Overall, the groundwater heat pumps that utilized the compressor for cooling operation had average SEERs between 7.6 and 8.9. Units using direct water-to-air cooling showed significantly higher SEERS, ranging from a low of 9.6 to a high of 14.0. Direct water-to-air cooling with earth-coupled heat pumps was attempted but was unsuccessful due to high earth loop temperatures (Hughes, 1986).

Domestic Hot Water Options

The earth-coupled heat pump project demonstrated three types of domestic water heating options:

1. Space heating and partial water heating
2. Space heating and total water heating
3. Separate heat pump solely for water heating

The total and partial water-heating options are similar in that an additional refrigerant-to-liquid heat exchanger is added to the basic heat pump. The heat exchanger is added between the compressor and the reversing valve. With the heat exchanger in this position, the highest temperature refrigerant is always available to heat water. With the total space heating and partial water-heating option, hot water can be produced whenever the heat pump activates for heating or cooling. The water heating is a free byproduct in the case of cooling operation.

A heat pump with the total water-heating option has the same basic configurations as the partial water-heating option, but differs in two key respects. First, due to modified controls, the heat pump can activate specifically for hot water production. Second, the additional heat exchanger is larger so that it can handle the entire output of the heat pump when required.

The separate domestic hot water heat pump is much smaller and less complex than the basic heat pump. No reversing valve is required because the unit is never used for cooling, and no fan or refrigerant-to-air heat exchanger is required because the unit only heats water.

SPF values for earth-coupled heat pumps with a partial water heating option averaged 2.4. Systems with total water heating averaged 2.5. The separate heat pump was inoperable at source temperatures below 36°F.

Earth-Loop Performance

Source and sink temperatures provided by earth loops are best understood by viewing some data examples. Figures 2 and 3 are provided for that purpose. These figures present data from Site 3 of the earth-coupled demonstration, which has a vertical earth loop. However, the temperature characteristics illustrated apply equally well to horizontal systems.

Figure 2 presents histograms comparing ambient and source temperature frequencies during times when the compressor operated over an entire heating season. The evident characteristics of earth-coupling is that it provides a floor for heat pump source temperature.

Figure 3 presents a trend plot of hourly source and ambient temperatures over a week of cold weather. The evident characteristics of earth-coupling is the relative stability of source temperature. Groundwater heat pumps exhibit similar characteristics except the source temperature generally falls around the 50°F line in Figure 3.

Groundwater System Performance

The groundwater system design and operation have an impact on the performance of the GWHP. The well pump size is one of the more important factors. The well pump power consumption rate for heating ranged from 0.41 kW to 2.12 kw for the houses in the project. The range of well pump power expressed in watts per gallon/minute was 47 to 247W/gpm. The flow rates corresponding to these values ranged from 4.1 gpm to 11.1 gpm. This range of well pump power differed from the American Refrigeration Institute standard of 63 W/gpm used by some GWHP manufacturers for system performance calculations.

Since increases in the well pump power will reduce the SPF, particular attention should be given to the pump size. Well pump power consumption is generally not linerally related to flow rate. Therefore, the operation of the GWHP at an off-design flow rate below the recommended flow may be more economical because reduced capacity is more than offset by well pump energy savings. Conversely, if the well pump is oversized, the flow rate may be increased without a significant increase in well pump resulting in an increase in SPF. The best approach is to properly size the well pump so that the optimum flow rate for the well pump matches the optimum flow rate of the GWHP. At less than optimum conditions, flow rate adjustments may improve system performance. The well pump energy consumption is particularly important at installations with direct water-to-air cooling. For example, at one direct water-to-air cooling installation, the well pump used more energy than the blower.

IMPACT OF GROUNDWATER AND EARTH-COUPLED HEAT PUMPS ON ELECTRIC UTILITIES

The components of a each system all require electricity for operation. Consequently, widespread installation and operation of these heat pumps within an electric utility's service area could have some impact upon the utility.

The two main factors to consider are: 1) the effect of on the demand curve and 2) the effect on total revenues. The overall effect will depend upon the percentage of the demand comprised by residential heating and if the electric utility's peak demand occurs during the summer or the winter.

The majority of the impact on electric utilities is likely to be related to the heating season. Unless the utility is a summer peaking utility and any additional summer peak load created by new heat pump air conditioning is a major concern, the impact of these heat pumps will be related to their heating operation.

Figure 4 shows the demand profile for a New York State electric utility on the day when its 1983-84 winter peak occurred. Figure 5 shows a demand profile for House 1 in the groundwater heat pump project on the coldest weekday of the 1983-84 winter. Earth-coupled heat pumps exhibit a similar demand profile to that shown in Figure 5.

Comparison of these figures shows that the total house peak demands coincided with the utility peak demands. Although the heat pump systems did not significantly alter the shape of house electric demand curves, they did provide a uniform base load. If less efficient electric heating systems had been used the house demand curves would have been shifted upward, resulting in higher peak demands.

ECONOMICS

The performance of groundwater and earth-coupled heat pumps is very similar so, for the purpose of presenting the economics, they will be treated together. The major energy savings from these systems is for space heating, although water heating also provides a significant savings potential. An attractive feature of owning a ground-source heat pump is that air conditioning is included. The performance of ground-source heat pump air conditioning is at least comparable to, and in many cases better than, the performance of a conventional air conditioner.

There are two factors to consider when evaluating the economics of ground-source heat pumps: (1) the annual operating cost savings and (2) the first cost of the system.

The operating cost savings are governed by the following factors:

- Cost of electricity.
- Performance of alternative heating systems.
- Cost of alternative fuels.
- Relative maintenance costs.

The initial cost will include the following components:

- Any retrofit duct system modification costs.
- Local excavating and exterior piping costs.
- Any well-drilling costs beyond those used for domestic purposes.
- Accommodations to groundwater discharge codes and ordinances.
- Cost of the heat pump and installations relative to the cost of alternative heating and cooling systems.

Space Heating Savings

The operating cost savings available depend on what fuel is currently being used on how much that fuel costs. Figures 6 and 7 graphically demonstrate the cost savings that can be achieved by using ground-source heat pumps versus oil and natural gas heating systems. For example, if you currently use oil at $1.20 per gallon, and electricity at 6.5¢/kWh, from Figure 6 you can determine that approximately 50% of your oil bill can be saved, or $452 of a typical $900 annual oil heat cost. Note that this figure does not account for the differential maintenance cost of different equipment, the expected useful life of the equipment, or the purchase costs of the equipment. The maintenance requirements for a ground-source heat pump should not exceed the combined maintenance requirements of a fossil-fired heating system and central air conditioner. On the other hand, reduced maintenance costs can be expected if the ground-source heat pump is replacing an air-source heat pump. The smaller range of source temperatures of the ground-source heat pump is less severe on the mechanical system.

Water Heating Savings

The savings available depend on what fuel is currently being used, how much the fuel costs, and which water-heating option is being considered. Figure 8 and 9 illustrate the savings that can be achieved with the various heat pump water-heating options versus electric and gas hot water heaters. For example, at a current cost of 6.5¢/kWh, Figure 8 shows that a partial water-heating option can reduce your electric water heating bill by about 23% or $86 of an annual $371 hot water bill.

Payback

Payback is calculated by dividing annual energy savings into the incremental installation cost. The best paybacks are available in new construction or where existing equipment requires replacement. Here the appropriate cost to use in the calculation of payback is only the difference in cost between a ground-source system and the conventional alternative.

For example, a typical replacement market three-ton earth-coupled heat pump system with partial water heating and a two-pipe-per-trench horizontal earth loop in a mature market might cost $5,400. However, if the homeowner needed to replace the oil furnace for $1,500 and planned to add central two-ton air conditioning for $1,600 the incremental installation cost is only

$2,300. Using the above examples, your annual energy savings for space heating and water heating are $452 an $86, respectively, or $538 total, resulting in a 4.3 year payback period.

Since ground-source heat pump systems provide both heating and cooling, their economic attractiveness is greatest when compared to an alternative system which includes air conditioning. Homeowners desiring both heating and cooling will certainly constitute the bulk of the market for this technology. If cooling is not desired, the first cost premium for this device is greatest, as will be the anticipated payback period.

To summarize, the important considerations are the savings that will be realized each year by installing a ground-source heat pump system versus the initial cost of a ground-source system. These considerations will vary depending upon local energy costs, the type of ground-source heat pump installation, and the cost of the ground-source heat pump system versus alternative heating systems.

TECHNOLOGY TRANSFER

The principal objectives of Phase 3 of the Residential Earth-Coupled Heat Pump Demonstration were: (1) to develop models to generalize site-specific results into a computerized predictive technique for earth loop sizing and ECHP system performance prediction in upstate New York, and (2) to document acceptable practices for residential earth-coupled heat pump system installation in upstate New York.

Model Developments or Adaptations of Existing Approaches

Two system model formulations were developed under this project. The first, hereafter referred to as the "Model for Design and Performance Prediction", is built around monthly bin analysis. This model meets the technical requirements set forth by the cosponsors, and serves as "raw material" for equipment suppliers interested in incorporating it into their market support software at their own expense.

The second system model, hereafter referred to as the "Simplified Model for Performance Prediction", is built around annual bin analysis. This model is derived from results generated by the monthly bin analysis model, and serves as "raw material" for utilities interested in incorporating it into their customer service software at their own expense. This software meets technical requirements which are appropriate for the "economic comparison of competing systems" application.

Two project deliverables, in addition to this report, are provided under separate cover. The Manual of Acceptable Practices is a "how to do it" book for upstate New York directed at contractors. The "Simplified Model for Performance Prediction" deliverable consists of a user's manual and IBM PC diskette for a computer program which analyzes earth-coupled heat pump systems only. This is the "raw material" which utilities can incorporate into their customer service software which compares commercially available residential heating and cooling systems (Hughes, 1986).

In addition to the Phase 3 effort, a separate technology transfer project was undertaken to disseminate the results of both the earth-coupled and groundwater heat pump demonstration projects. Under this project a ground-source heat pump technical guide was published describing earth-coupled and groundwater heat pump systems, installation practices, performance characteristics and system economics. The guide was distributed to prospective New York State ground-source heat pump dealers and installers including HVAC contractors and dealers, well drillers, excavators, design engineers and architects. In addition, a leaflet was produced providing a general description of ground-source heat pump systems and was targeted more for the uninformed public.

A ground-source heat pump seminar was also produced to introduce the technology, demonstrate installation and maintenance procedures and discuss economic benefits of ground-source heat pumps. Topics for discussion during the seminar included the results from the recent earth-coupled and groundwater heat pump demonstration projects, presented by the principals of the two projects, as well as practical field experiences as discussed by several manufacturers. The seminar will be offered throughout a number of upstate utilities' franchise territories in the coming Fall.

CONCLUSIONS

A primary advantage of ground-source heat pumps over other heating systems is their ability to efficiently produce hot water, as well as thermal comfort, all year long. And, depending on the application, the homeowner can benefit from substantial heating cost savings, significant water heating cost savings, and some cooling savings. A payback period of 3 to 10 years is likely. Additionally, everyone benefits when utilities experience a more uniform load. Ground-source heat pump systems have proven to be a highly effective load management and conservation tool, demonstrating electric demands of only one-third to one-half those of competing electric heating systems on winter peak days, while their electric consumption during the rest of the heating season is more uniform. They also show slightly lower electric demand on summer peak days.

FOOTNOTES

(1) Blake, P.J., et.al., Heat Pump Monitoring, ESEERCO Research Report EP5-6, Final Report, October 1980.

(2) Hughes, P.J. Residential Earth-coupled Heat Pump Demonstration Phases 1 and 2. NYSERDA, January, 1986.

(3) Hughes, P.J. Residential Earth-coupled Heat Pump Demonstration - Phase III. NYSERDA, 1986.

(4) Rackliffe, G.B. Ground Water Heat Pump Evaluation. ESEERCO, April, 1985.

INTERVAL ENDING	AMBIENT TEMPERATURE HOURS IN INTERVAL	LIQUID SOURCE TEMPERATURE HOURS IN INTERVAL
-15.00	0.00	0.00
-10.00	0.00	0.00
-5.00	16.00	0.00
0.00	28.00	0.00
5.00	77.00	0.00
10.00	131.00	0.00
15.00	159.00	0.00
20.00	240.00	0.00
25.00	359.00	0.00
30.00	386.00	0.00
35.00	630.00	80.00
40.00	608.00	1937.00
45.00	420.00	1086.00
50.00	261.00	375.00
55.00	101.00	0.00
60.00	38.00	0.00
65.00	20.00	0.00
70.00	1.00	0.00
75.00	3.00	0.00
80.00	0.00	0.00
85.00	0.00	0.00
90.00	0.00	0.00
95.00	0.00	0.00
100.00	0.00	0.00
TOTAL	3478.00	3478.00

Figure 2. Ambient vs. source temperature histogram

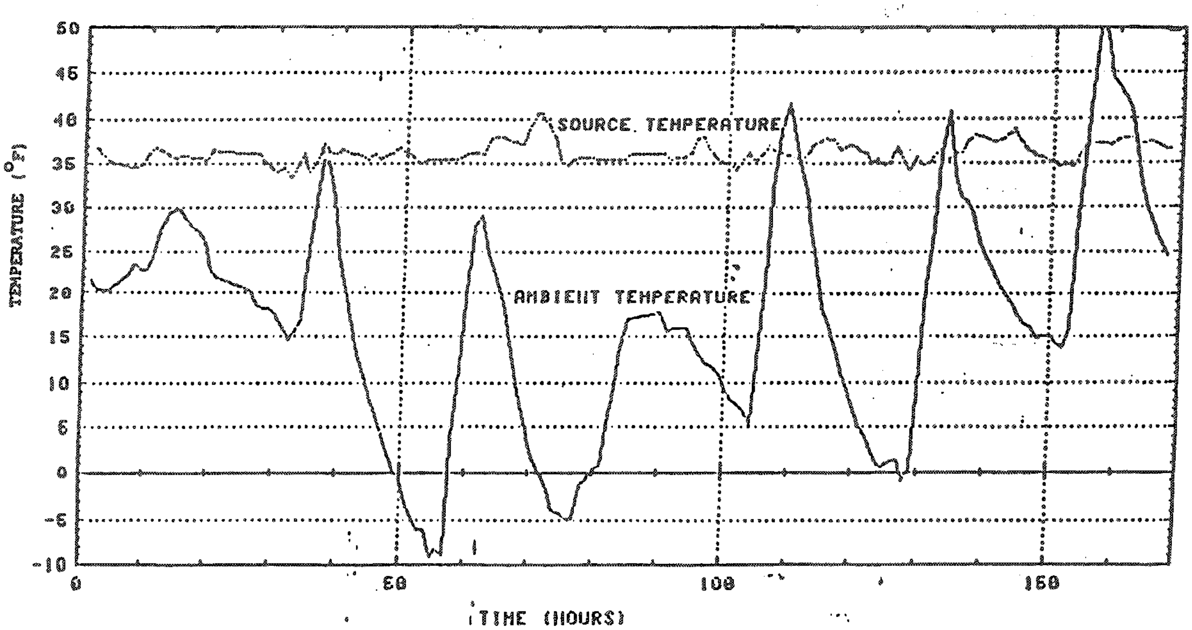

Figure 3. Hourly temperature trends.

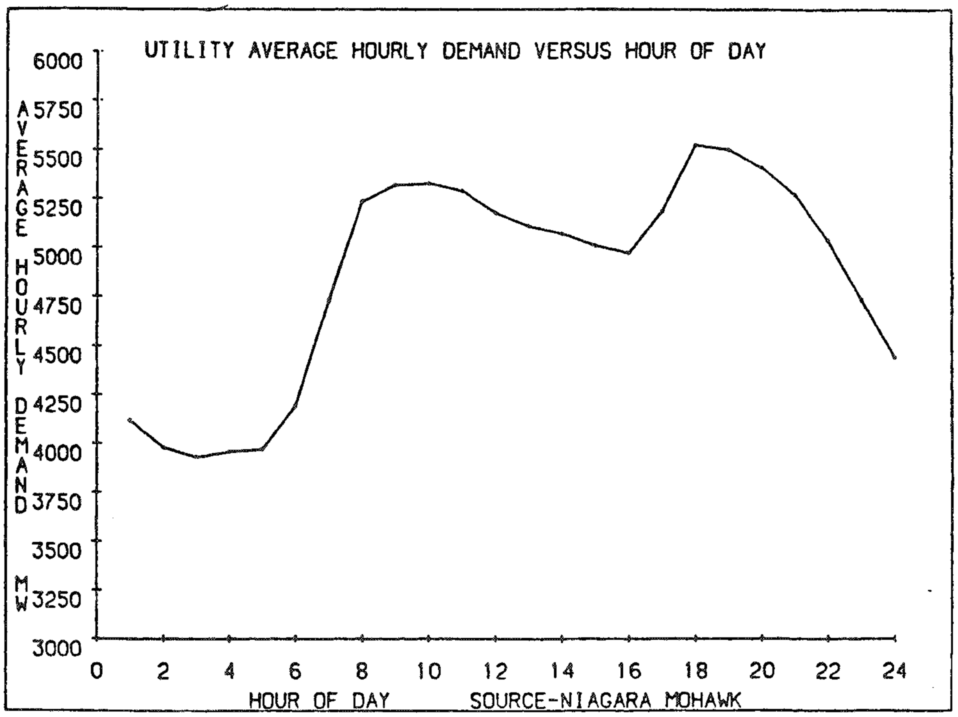

Fig. 4 Utility Average Hourly Demand versus Hour of Day

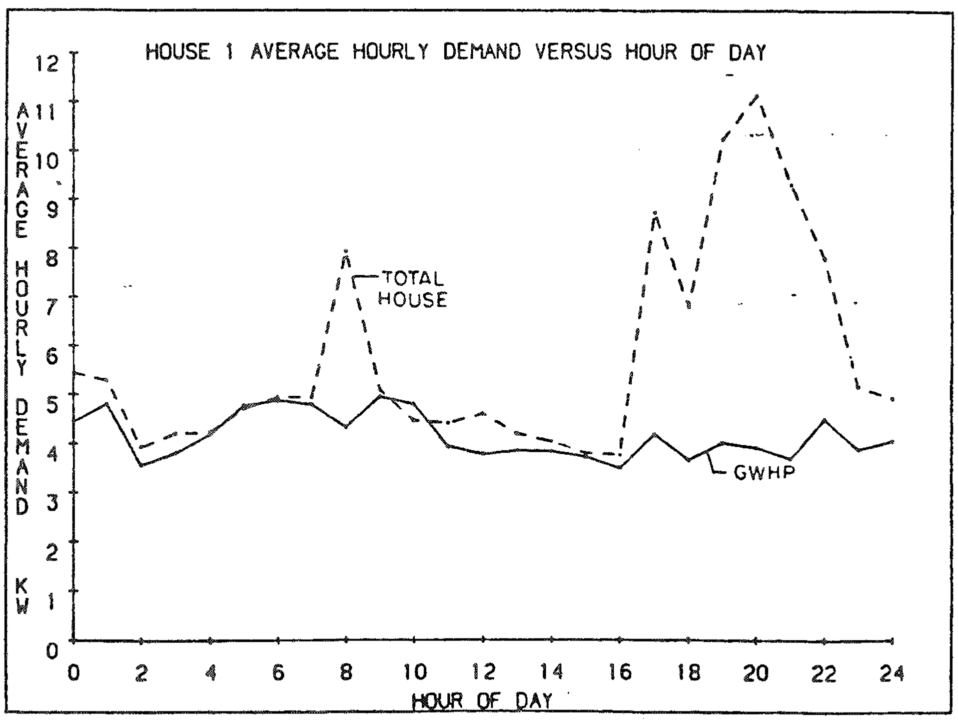

Fig. 5 House 1 Average Hourly Demand versus Hour of Day

1.17

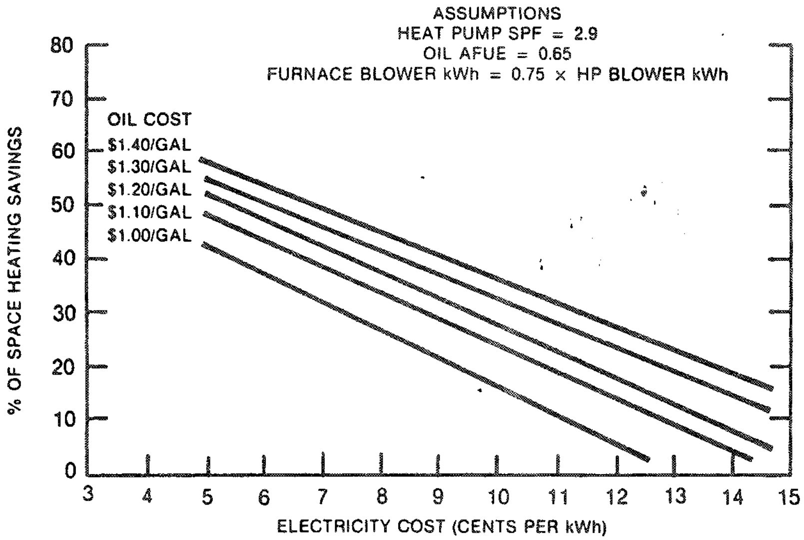

Figure 6 Space Heating Savings—Ground-Source Heat Pump vs Oil Heating

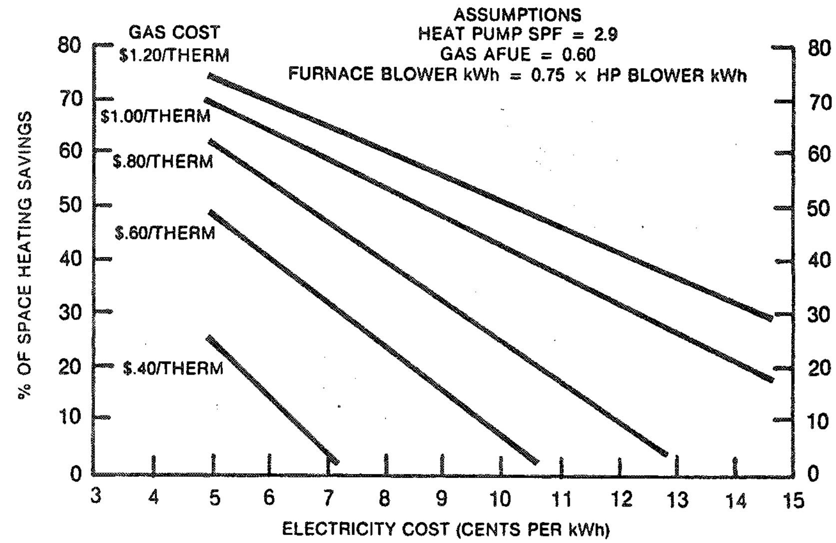

Figure 7 Space Heating Savings—Ground-Source Heat Pump vs Natural Gas

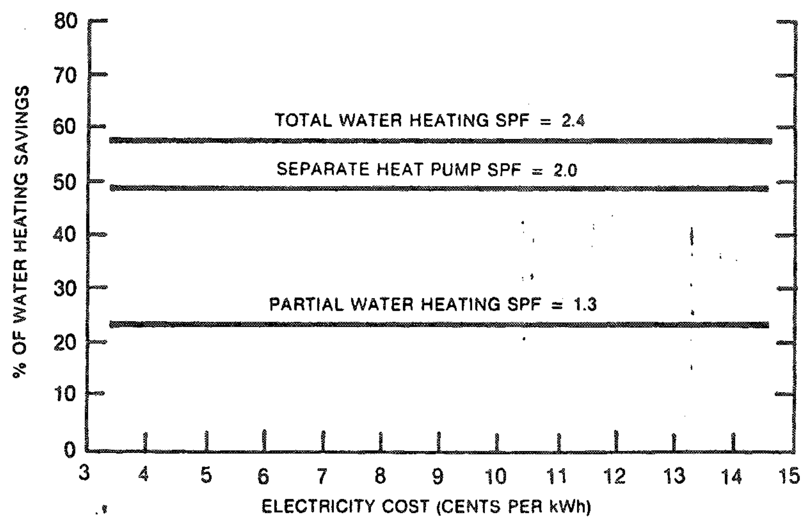

Figure 8 Water Heating Savings—Ground-Source Heat Pump vs Electric Hot Water Heater

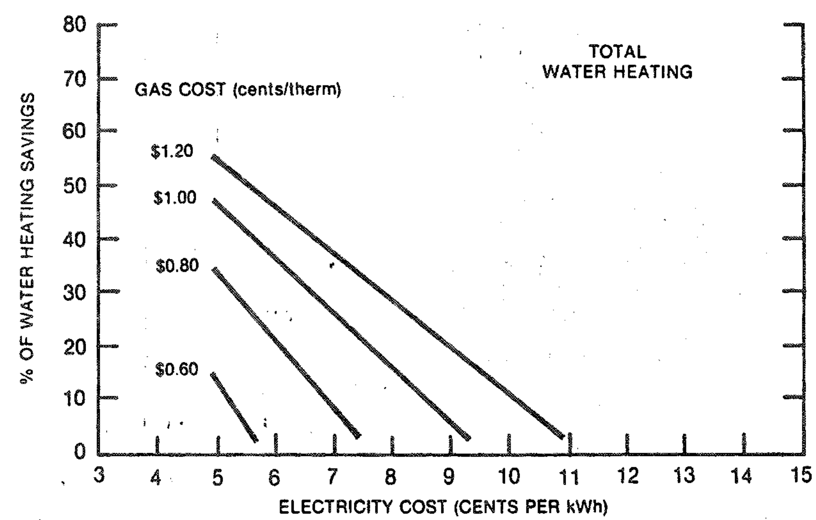

Figure 9 Water Heatings Savings—Ground-Source Heat Pump vs Natural Gas Hot Water Heater