A ground-source heat pump in Northern climates

**Summary**

A small office building in New York State was retrofitted with a ground-source heat pump (GSHP) system and was studied from 1982 through 1984. Eight different vertical earth coil heat exchanger (ECHX) configurations were tested. The most cost-effective for this building was the parallel-connected, multiple borehole arrangement with six small diameter vertical pipe loops per borehole. With aggressive utility demand-side management (DSM) programmes and incentives, GSHP systems can be cost-effective even when compared to gas systems. Some of the non-economic advantages include reduced maintenance, increased equipment lifespan, system security, and improved aesthetics.

**Highlights**

- Reduced electric peak demand.
- Efficient space heating and cooling.
- Improved installation techniques.
- Cost-effective for new small-to-medium sized buildings.

Small commercial building hosting the demonstration.
Aim of the Project

The objective of this project was to acquire data and knowledge about a GSHP system operating in a typical small commercial building under extreme heating and cooling load conditions. The knowledge gained from this project would be used to determine the benefits of this technology for utilities and end-users; to develop design recommendations for the application of these systems to medium-sized commercial buildings; and to gain experience in the design, construction, installation, operation, and maintenance of these systems to help the building and contracting trades.

The Principle

Four key design parameters for vertical ECHXs were isolated and tested in this demonstration project: series versus parallel connection; pipe density per hole; depth of hole; and pipe size. Eight ECHX configurations were evaluated, including two deep borehole types (two pipes per hole and six pipes per hole, both parallel) and six shallow borehole types (one pipe per hole, series and parallel; two pipes per hole, series and parallel; four pipes per hole, parallel; and six pipes per hole, parallel). All boreholes were 15.2 cm (6") in diameter.

The Situation

Since 1982 Niagara Mohawk Power Corporation (NMPC) has been involved with residential GSHP systems, performing field trials and monitoring and analyzing the results. GSHP systems were confirmed to be cost-effective for residential customers and provide demand-side management benefits for electric utilities. However, insufficient knowledge was available about using GSHP applications for small commercial buildings. Approximately 13% of NMPC’s total annual electrical sales over the past ten years has been for commercial heating and cooling, compared to 3% for residential space heating and cooling; therefore, to provide valuable information for NMPC and its small-to-medium commercial building customers, a small office building in Syracuse, New York, was retrofitted with a GSHP system incorporating the eight different vertical ECHX configurations.

Figure 1: Design of the least-costly ECHX configuration for this demonstration.

Production of the heat exchangers required the preparation of twenty-nine holes. Seventeen holes were dug with a trenching machine equipped with a drilling rig and twelve holes with a hollow stem auger rotary drilling machine equipped with a similar, but larger, drilling rig. The least cost per hole averaged USD 1,000 using the trenching machine and USD 800 using the hollow stem auger. The drilling technique of the hollow stem auger eliminated the hole casings and mud trenches that were necessary when using the trenching machine. After completing the hole drilling, the pipe loops were fabricated and inserted into the holes; trenches were cut between the holes and to the building as required; and horizontal pipe runs providing hole inter-connections and entrance into the building were installed.

System monitoring during the test period showed that the minimum water temperature entering the heat pumps was about 1.7°C (35°F) in a heating climate area with 3,780
degree-days (6,800°F-days). The peak water temperature was about 26.7°C (80°F), concurrent with ambient temperatures above 26.7°C (80°F). Monitoring of the system since 1986 has shown that these minimum and maximum water temperatures have remained approximately the same. The influence of the horizontal pipe runs (supply and return) was considerable. For instance, during the heating season, heat exchange in these runs was nearly always counter to the loop heat exchange. It was determined that the horizontal pipe runs in vertical ECHX configurations should be insulated in geographic areas with high heating and cooling loads.

Parallel-connected configurations were nearly 30% less costly than the series-connected configurations. The most cost-effective ECHX for the small office building used in this demonstration had the characteristics shown in the box above.

### The Organisation

The Fleming Group (TFG), which has its headquarters in Syracuse, New York, was formed in 1975. The staff of 55 professionals provide services relating to technology, energy, and environment to clients around the world. Total revenue for 1989 exceeded USD 5.4 million.

### Economics

Within the new construction market, the GSHP systems can be cost-effective for small-to-medium sized commercial buildings compared to conventional systems which have high electricity demand charges and, thus, high operating costs. It is also cost-effective when compared to systems with relatively high installation costs. The GSHP system can be marginally cost-effective when compared to other relatively energy-efficient systems, for example, the air-to-air heat pump system. If the electric utility provides aggressive DSM incentives, then this system can be quite cost-effective when compared to all other conventional systems considered, including the natural gas system.

As the market has matured, the cost of ECHXs for GSHP systems has been reduced 30% for vertical coils and 46% for horizontal coils compared to the lowest cost vertical coil construction in the demonstration project.

**Table 1** presents simple payback periods of commercial GSHP systems, both with and without DSM incentives, compared to those for four conventional heating and cooling systems. A simple payback period here represents the time, in years, necessary for the GSHP energy cost savings to equal the incremental installation cost of the GSHP system over the conventional system. After this time period the energy cost savings would be a positive cash flow to the building owner.

<table>
<thead>
<tr>
<th>Characteristics of a demonstration small office building.</th>
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<tbody>
<tr>
<td><strong>Type:</strong> Multiple deep borehole, vertical loop due to limited available land area.</td>
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<tr>
<td><strong>Pipe Arrangement:</strong> Parallel-connected, utilizing a smaller diameter pipe and thus reducing the piping costs. The smaller pipe is also easier to work with during the installation. (See Figure 1.)</td>
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<tr>
<td><strong>Pipe Configuration:</strong> Six 1.9 cm (3/4&quot;) pipe loops in each 91.4 m (300 ft.) borehole.</td>
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<td><strong>Total ECHX Cost:</strong> USD 18,176.</td>
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ECHX connections in the mechanical room of the building.
Table 1: Simple payback periods of GSHP systems vs conventional systems.

<table>
<thead>
<tr>
<th></th>
<th>Without DSM Incentives</th>
<th>With DSM Incentives</th>
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<tr>
<td>Commercial GSHP vs:</td>
<td></td>
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<tr>
<td>vertical GSHX</td>
<td></td>
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<tr>
<td>horizontal GSHX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Electric heating</td>
<td>4.2 yrs</td>
<td>2.9 yrs</td>
</tr>
<tr>
<td>with DX cooling</td>
<td>2.2 yrs</td>
<td>0.9 yrs</td>
</tr>
<tr>
<td>2. Gas heater with</td>
<td>22.6 yrs</td>
<td>15.0 yrs</td>
</tr>
<tr>
<td>DX cooling</td>
<td>7.6 yrs</td>
<td>1.9 yrs</td>
</tr>
<tr>
<td>3. Air-to-air heat</td>
<td>6.7 yrs</td>
<td>3.4 yrs</td>
</tr>
<tr>
<td>pump with electric</td>
<td>3.7 yrs</td>
<td>1.4 yrs</td>
</tr>
<tr>
<td>back-up</td>
<td>1.4 yrs</td>
<td>0.2 yrs</td>
</tr>
<tr>
<td>4. Water source</td>
<td>1.4 yrs</td>
<td>0.2 yrs</td>
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<tr>
<td>heat pump with</td>
<td></td>
<td></td>
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<tr>
<td>boiler/evaporator</td>
<td></td>
<td></td>
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<tr>
<td>cooler</td>
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</tbody>
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IEA

The IEA was established in 1974 within the framework of the OECD to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the 24 IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology, and research and development (R&D).

This is achieved, in part, through a programme of energy technology and R&D collaboration currently within the framework of 40 Implementing Agreements, containing a total of over 70 separate collaboration projects.

The Scheme

CADDET functions as the IEA Centre for Analysis and Dissemination of Demonstrated Energy Technologies. Currently, the Energy Efficiency programme is active in 15 member countries.

This project can now be repeated in CADDET Energy Efficiency member countries. Parties interested in adopting this process can contact their National Team or CADDET Energy Efficiency.

Demonstrations are a vital link between R&D or pilot studies and the end-use market. Projects are published as a CADDET Energy Efficiency 'Demo' or 'Result' respectively, for ongoing and finalised projects.

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