Operating Experiences with Commercial Ground-Source Heat Pump Systems

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Table of Contents

FOREWORD

This document contains engineering case studies of nine commercial/institutional buildings with ground-source heat pump systems. Each case study contains information on the reasons for installing a ground-source system, a detailed description with schematics of the interior and exterior system design, sections presenting data on capital costs and annual energy performance, a discussion of operating difficulties with the system, and owner satisfaction to date.

A capital cost comparison between the ground-source system and a conventional HVAC system is presented in each case. In most cases, ground-source system capital costs are based on actual data from the sites. The conventional system costs were based on feasibility study results, where available. Where capital cost estimates for conventional systems were not available, these were prepared by Caneta Research based on conventional HVAC system design practice and the use of R.S. Means data for capital cost estimates. It was felt that this would have been the approach used by the original proponents in preparing a feasibility assessment.

Annual energy performance estimates for the ground-source heat pump systems were based on submetered energy use or were estimated from the building's utility bills. Where conventional HVAC system energy use estimates were not available, monthly heat pump consumption was converted to space heating and cooling loads using heat pump performance ratings. Conventional HVAC equipment efficiencies were then used to convert the space heating and cooling loads to energy consumption. Energy use estimates for auxiliary equipment such as cooling towers, fans, and pumps were added as required to the heating and cooling equipment energy consumption estimates to obtain the total conventional HVAC energy consumption.

This document presents many examples of commercial ground-source system design and operating experience. The design, performance, and cost characteristics of the nine sites discussed in this document are summarized in the accompanying tables. It is not intended that the design characteristics of these buildings be used for anything more than a starting point for the design of new projects. Readers are encouraged to consult published engineering design manuals, available through ASHRAE, and to utilize software programs for sizing ground heat exchangers to ensure that the latest techniques and information are employed in designing commercial ground-source heat pump systems.

Table 1
Ground-Source System Summary

Characteristic	Average	Range
Electricity Costs ($/kWh)	0.079	0.049 - 0.161
Natural Gas Costs ($/therm)	0.71	0.43 - 1.140
Building Floor Area (ft^2)	45,900	8,000 - 181,069
Total Installed Heat Pump Capacity (tons)	111	24 - 410
Capacity or Heat Pump System Size (tons/100 ft^2)	2.81	1.45 - 3.95
Vertical Borehole Length (ft/ton)	131	92 - 176
Flow Rate (gpm/ton)	2.46	0.4 - 3.20
Loop Pump Size (HP/ton)	0.11	0.04 - 0.21
Ground Heat Exchanger Cost ($/ft bore)	8.84	3.00 - 18.18
Ground Heat Exchanger Cost ($/ton)	1,090	353 - 2,513

Table 2
Conventional vs. Ground-Source Summary

Characteristics	Average of Conventional	Average of Ground-Source	Range of Conventional	Range of Ground-Source
Total Building Energy Use (ekWh/ft^2/y)	22.70	14.37	12.80 - 49.40	8.10 - 22.30
Total Building Peak Demand (W/ft^2)	7.18	4.72	3.46 - 12.50	2.31 - 9.38
Total Building Energy Costs ($/$ft^2$/y)	1.28	1.02	0.79 - 2.07	0.62 - 1.43
Installed HVAC System Capital Cost ($/$ft^2$)	7.96	9.32	2.19 - 13.78	2.67 - 16.35
Simple Payback Period (Years)	–	5.94	-	immed. - 12.4
Return on Investment(%)*	-	19.0	-	6 - ∞

* Return on investment assumes 20-year life and 1% real energy escalation rate. The return on investment is the internal rate of return that would prevail if the present worth of the energy savings over the life of the investment just equalled the initial investment. Compare this with expected rates of return on other investments.

ACKNOWLEDGMENTS

The research and analyses of the case studies were a team effort. The team was headed by Caneta Research Inc., Mississauga, Ontario, and included the Cadmus Group Inc., Waltham, Mass., and the Science Applications International Corp. (SAIC), East Syracuse, N.Y.

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We would like to acknowledge the cooperation and assistance of the owners and contacts at the various sites without whom this investigation would not have been successful. These individuals deserve special mention for responding to the many and varied questions raised by the team over the course of the investigation.

The team would also like to acknowledge the peer review organized by ASHRAE TC 6.8 and the many useful comments and revisions that resulted.

CHAPTER 1

FATHER MICHAEL MCGIVNEY SECONDARY SCHOOL

BACKGROUND

Father Michael McGivney Secondary School is a three-story, 181,000 ft^2 building located in Markham, Ontario, just north of Toronto. Built in 1992, the school has 38 classrooms, 19 laboratories and workshops, a library, administrative offices, a chapel, a greenhouse, a cafeteria, three gymnasiums, and a child care center. The full occupancy of the school is about 2,400 staff and students.

The building sits on a poured concrete foundation and is slab on grade. Its exterior is brick veneer over a concrete block wall. The walls and roof are insulated to R-16. Windows are double glazed, and there is a window-to-wall ratio of about 10%.

The decision to install a ground-source system at the school was supported by two economic reasons:

- The electric utility offered a very attractive ground-source incentive.
- The use of a ground-source system reduced the size of the required equipment room, freeing space for classroom area, which is the basis for government grants.

SYSTEM DESCRIPTION

The ground-source heat pump (GSHP) system contains 97 water-to-air heat pumps installed in hallway ceiling spaces outside individual classrooms and offices and 20 water-to-water heat pumps located in three mechanical rooms. The total installed cooling capacity on the loop is 410 tons. The heat pumps are connected to a two-pipe distribution system served by two 50-hp circulating pumps that alternate service, with the on-service pump operating continuously. The water-to-water heat pumps heat service hot water and preheat and precool ventilation air (see Figure 1). The heat pump preheats and precools the ventilation air downstream of a heat pipe-type heat recovery unit. The heat recovery unit has a capacity of 1,764 MBtu (517 kW) at the winter design condition. An energy management system maintains indoor temperatures at 72°F, allowing a setback to 60°F for nights and weekends during the heating season.

The ground heat exchanger system consists of 360 vertical U-tubes 200 feet deep for a total of 72,000 feet of vertical borehole (see Figure 2). The U-tubes are constructed of nominal 1¼-inch series 160 (SDR

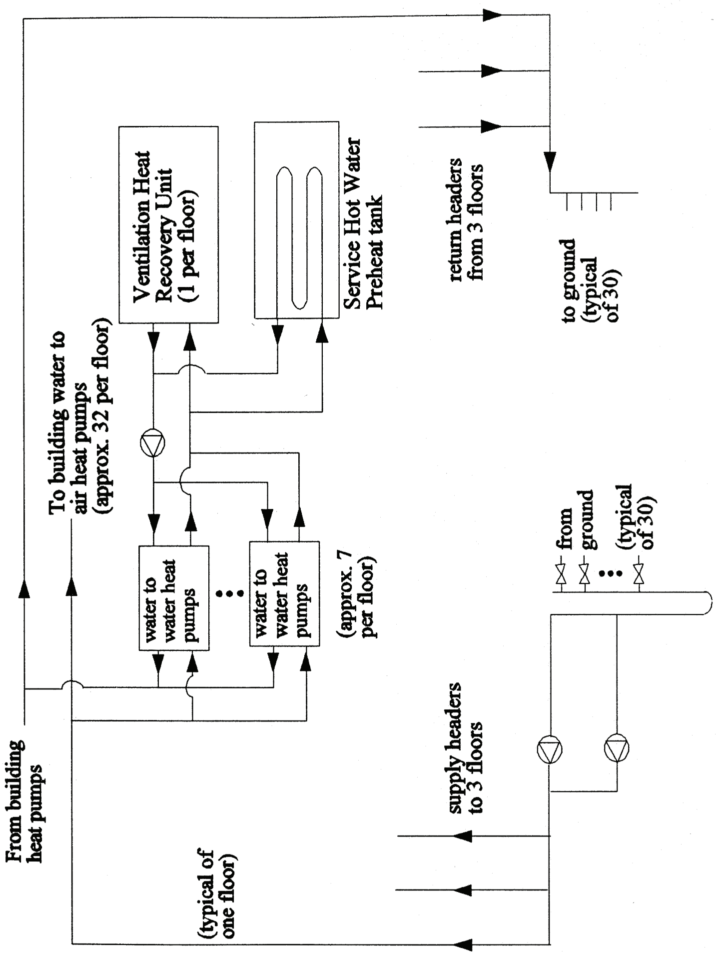

Figure 1-1 *Internal piping.*

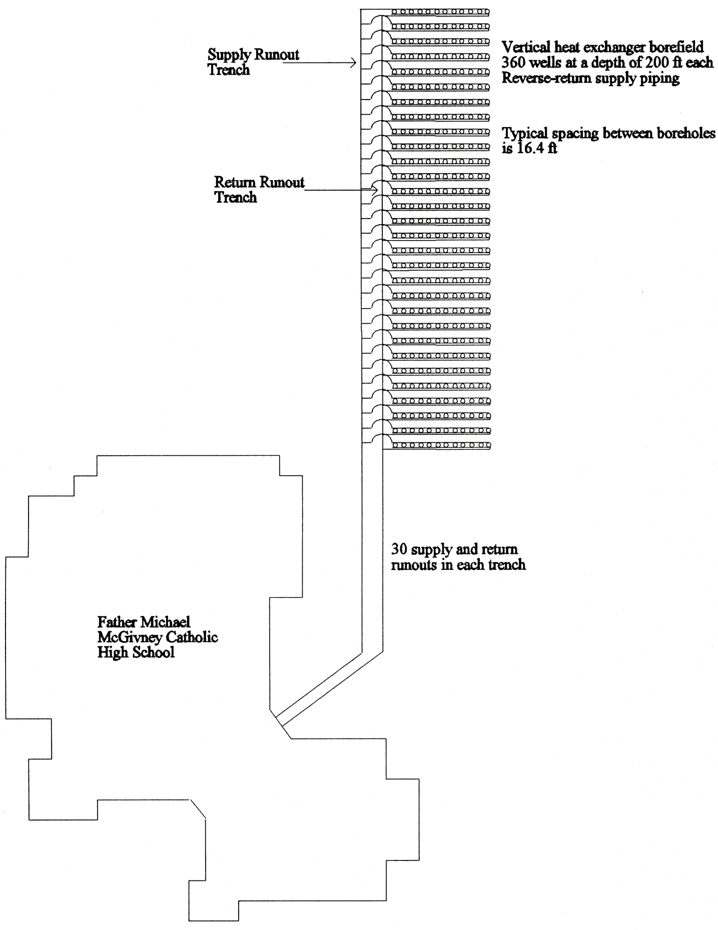

Figure 1-2 *Site plan.*

11.0) polyethylene pipe connected to nominal 2-inch series 160 (SDR 11.0) header pipe. The distance between boreholes is 16.4 ft. The rectangular borefield is large enough that return water temperatures do not approach freezing, allowing water to be used as the heat exchanger fluid.

PROJECT COSTS

The total cost of the heating, ventilating, and air-conditioning (HVAC) system—including ground coupling, heat pumps, and ventilation—was almost $2.6 million, as shown in Table 1-1. This total includes the cost of the energy management system, which was almost $200,000. These values were supplied by the engineering firm that designed the HVAC system. A conventional variable-air-volume (VAV) system with a gas boiler and water chiller would cost almost $2.5 million, based on cost estimates from EPRI, the Mean's directory, and the

Table 1-1
Father Michael McGivney—Capital Costs

	Actual GSHP System Costs	Estimated Conventional System* Costs
Heat Pumps	232,700	–
Underground Heat Pump System	1,030,200	–
Piping	312,000	526,700
Air Handling and Ducting	665,450	701,700
Insulation—Ducting	102,000	102,000
Insulation—Piping	43,550	–
Energy Management System	195,000	195,000
Start-up	15,000	15,000
Terminal Units	–	162,000
Chiller/Cooling Tower	–	157,000
Pumps	–	39,200
Boiler	–	187,300
Radiators	–	40,200
Additional Construction Costs	–	225,800
Other	–	127,100
Total	$2,595,900	$2,479,000

* VAV system with a water-cooled chiller and gas-fired perimeter radiation heating.

ground-source system cost breakdown. The conventional HVAC system would require an estimated $225,800 in additional construction costs. A conventional system is more costly to construct because it requires more floor-to-floor space for the forced-air system and additional mechanical room space for the chiller and boiler. The capital costs of the GSHP system were $116,900 more than that of the central chiller/gas boiler VAV system.

SYSTEM PERFORMANCE

Although an energy management system is installed in the building, no attempt has been made to retain or analyze information available from it. The only energy information available comes from utility billings and from an hourly energy simulation analysis performed shortly after the school was constructed. The actual energy consumption shown in Table 1-2 is for February 1995 to January 1996. The gas consumed in the building with the GSHP system was used for laboratories and kitchen appliances. Six portable classrooms with electric resistance heating were recently installed at Father McGivney. Their estimated

Table 1-2
Father Michael McGivney—Annual Energy Performance

	GSHP System		Conventional System*
	Actual	**Predicted**	**Estimated**
Total Building			
Electricity (kWh)	2,460,239	2,389,070	2,164,152
Peak Demand (kW)	736	774	626
Natural Gas (therm)	5,440	5,440	79,900
Energy Cost ($Cdn)	191,260	185,810	200,678
HVAC System			
Peak Demand (kW)		381	-
Heat Pumps (kWh)	-	551,184	-
Circulating Pumps (kWh)	-	331,860	-
Averaged Unit Energy Costs†			
Electricity	$0.0765/kWh	$0.0765/kWh	$0.0765/kWh
Natural Gas	$0.56/therm	$0.56/therm	$0.49/therm

Note: "-" stands for "not available."

* VAV system with a water-cooled chiller and gas-fired perimeter radiation heating.

† Equal to all demand and energy charges divided by metered energy.

energy consumption was deducted from the total metered energy consumption.

The performance of the ground-source system was predicted based on a building energy analysis program. The performance of the conventional system was based on the energy use of a school with a VAV system using a water-cooled chiller and gas-fired perimeter radiation heating. The conventional school is similar in size to Father McGivney and is within the same school district. Based on analysis of the utility bills, the ground-source system saves $9,420 annually in energy compared to a central chiller/gas boiler system.

Using an hourly energy simulation program, the HVAC system in the actual school was estimated to consume 883,000 kWh annually. The constant speed circulation pumps were estimated to consume approximately 331,860 kWh, or 38% of the total HVAC energy. The cost of operating the circulation pumps was approximately $25,400.

Based on the system project costs shown in Table 1-1, including the additional construction cost estimate from the engineer, the ground-source heat pump system has a simple payback period of 12.4 years. The payback period is further reduced for the County Board of Education by an electrical utility incentive for the ground-source system.

Operating Difficulties

The ground-source system had a number of commissioning problems.

- Some of the water-to-water heat pumps for the heat recovery system were running even though the outside air supply had been shut off.
- Leaky automatic air-purge valves were causing low water levels in the secondary water/glycol loop, leading to automatic shut-off of the heat recovery units.
- Twenty-one of 97 water-to-air heat pumps had heating problems due to improper water flow rates, low refrigerant charges, or defective reversing valve relays.

Owner Satisfaction

The system is currently operating within the expectations of the owner. An indication of the school board's satisfaction with the ground-source heat pump system is the fact that such systems have been installed in seven new schools in recent years.

Subsequent to the commissioning, the only maintenance or service that has been performed on the HVAC system at Father McGivney is routine filter cleaning and the unplugging of several blocked condensate drains.

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BUILDING SUMMARY

Building Description

Occupancy: Secondary School

Location: Markham, Ontario

Gross floor area: 181,069 ft^2

Number of stories: 3

Type of building construction: New

Completion date: 1992

Degree-days: Cooling (50°F): 2,013
Heating (65°F): 7,765

Ground-Source Description

Overburden depth: 85 ft

Overburden material: Fine to coarse sand

Bedrock material: Limestone

Mean annual ground temperature: 50°F

Interior System

Total installed heat pump capacity: 410 tons

Number of heat pumps: 97 water-to-air, 1 to 25 tons each; 20 water-to-water, 5 tons each

Internal fluid distribution system: Water-loop
Flow rate/installed capacity: 3.2 gpm/ton

Installed pump sizes: 2 × 50 hp

Operating pump size: 0.12 hp/ton

Additional systems and features:

- Outdoor air preconditioning with loop connected water/water heat pumps.
- Service hot water preheating with loop connected water/water heat pumps.

Energy Consumption and Peak Demand

Annual electrical use—building: 13.6 kWh/ft^2

Annual electrical use for HP system: 4.9 kWh/ft^2

Peak electric demand for building:
626 kW (summer), 736 kW (winter)

Peak electric demand for HVAC system: 381 kW

Type of Ground-Source System

Vertical closed loop

360 boreholes at 200 ft
Total borehole length: 72,000 ft

Total heat exchanger length: 144,000 ft

Borehole length per ton: 176 ft/ton
Heat exchanger pipe: 1¼ in. HD polyethylene

Secondary heat transfer fluid: Water

Flow rate through ground loop: 1,320 gpm

Economic Analysis

Building HVAC capital costs: $2,595,900

Annual GSHP building energy costs:
$191,260 ($1.06/ft^2)

Conventional HVAC capital costs: $2,479,000

Conventional HVAC energy costs:
$200,700 ($1.11/ft^2)

Cost of ground coupling: $14.31/ft borehole

Estimated simple payback period of GSHP system over conventional: 12.4 years

Utility/government incentive: Yes