RENEWABLE ENERGY

Earth Energy Systems

Case Study

Volume 1
Issue 1

Federally Sentenced Women's Facility

Federally Sentenced Women's Facility, Truro, Nova Scotia.

Background

The Federally Sentenced Women's Facility is a 41,300 ft^2 complex in Truro, Nova Scotia. The facility is composed of 12 one- and two-story buildings including residential units, a gymnasium, recreation building, education building, office areas, health/food services, and an enhanced security building. The full occupancy of the complex is approximately 35 inmates and staff.

The Federally Sentenced Women's Facility was constructed in 1994 to accommodate Correctional Service of Canada's Green Plan initiatives. To help the facility meet the Green Plan's carbon dioxide reduction targets, a closed-loop ground-source heat pump system was installed.

A radiant floor heating system was selected by Correctional Service for security purposes. Hot water pumps are used to circulate the water heated by the water-to-water heat pumps through piping located below the floors.

Correctional Service also desired supplemental propane heating in case of any problems with the heat pump system. The supplemental heating is provided by the solar hot water (SHW) boilers through water-to-water heat exchangers.

Two of the 20 heat pumps are serviced by a variety of spiral and slinky heat exchangers. These were included in the project for research purposes to evaluate their performance for future prison installations.

System Description

The ground-source heat pump system consists of twenty 3-ton water-to-water heat pumps located in mechanical rooms of the buildings with other equipment such as service water heaters. The heat pumps at the Truro prison are connected in series with the ground heat exchangers.

The heat exchanger fluid passes through a heat pump, then a ground heat exchanger, and back through another heat pump. This results in an extremely low flow rate and pump size relative to the installed heat pump capacity. The high-efficiency heat pumps provide hot water for the radiant floor space heating and duct heating coils. The heat pumps are isolated from the interior hot water distribution system and the ground loop by two hot water buffer tanks. Hot water is also supplied by solar hot water systems that are incorporated into six of the heat pump system designs. In addition, hot water can be provided to the interior loop buffer tank by the propane service hot water heater. The ground heat exchangers cool approximately 30% of the complex, including the administration areas occupied by prison staff, by passing water from the ground heat exchanger through the duct cooling

coils. The remainder of the complex, which includes the gymnasium and inmate quarters, is not cooled. Figure 1 illustrates the layout of the interior heat pump system. An energy management system (EMS) controls and monitors the heating and cooling equipment.

The refrigeration equipment in the food preparation area of the complex is also connected to the ground heat exchanger system. This eliminates the need for air-cooled condensers, and the otherwise

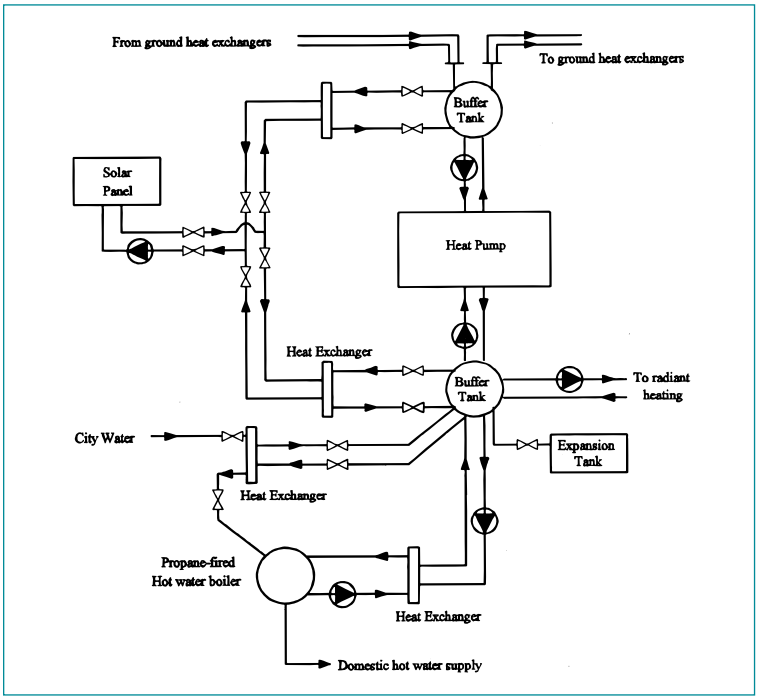

FIGURE 1 Interior Piping

rejected heat can be used elsewhere in the complex where it is needed. Ventilation air is provided by heat recovery ventilators (HRVs) with supplemental heating provided by the hot water coils. The gymnasium ventilation is heated with a propane-fired duct heater.

The ground heat exchanger, as shown on the site plan (Figure 2), consists of a variety of configurations separated into two isolated parallel loops, each serving half of the ground-source heat pumps. The heat pumps are connected in series with the ground heat exchanger, which also serves as the heat pump water loop. The flow from each heat pump is further subdivided into two parallel flows before it passes through the ground heat exchanger. The parallel paths of the horizontal heat exchangers are located in separate trenches. The parallel paths of the vertical heat exchangers are U-tubes located in the same borehole. Each heat pump is connected to the ground heat exchangers by supply and return headers that divide the heat pump flow into the two parallel loops.

The ground heat exchanger consists of a variety of configurations...

The ground heat exchangers include three different types of slinky heat exchangers layed flat on the trench bottom, a cylindrical spiral heat exchanger (svec spiral), and 24 vertical boreholes, 23 of which contain two U-tubes. The three slinky heat exchangers are defined as the "American slinky" (spiral pitch << spiral diameter), the "Bill Van Alstine extended slinky" (spiral pitch $\cong$ spiral diameter), and the "Lynn Vick extended slinky" (spiral pitch > spiral diameter). The depth of the boreholes ranges between 72 ft and 289 ft, and the total borehole length is 4,950 ft. There is approximately 650 ft of horizontal heat exchanger trench that services 6 tons of the 60-ton installed capacity. The minimum distance between boreholes is 16.4 ft. Two 1 1/2 hp pumps circulate the fluid through the two parallel heat pump/ heat exchanger loops at a rate of 12 gpm for a total heat exchanger flow of 24 gpm. The low flat rate is a result of the heat pump and heat exchangers being connected in series. Balancing valves are used to maintain equal flow through the two parallel heat exchangers.

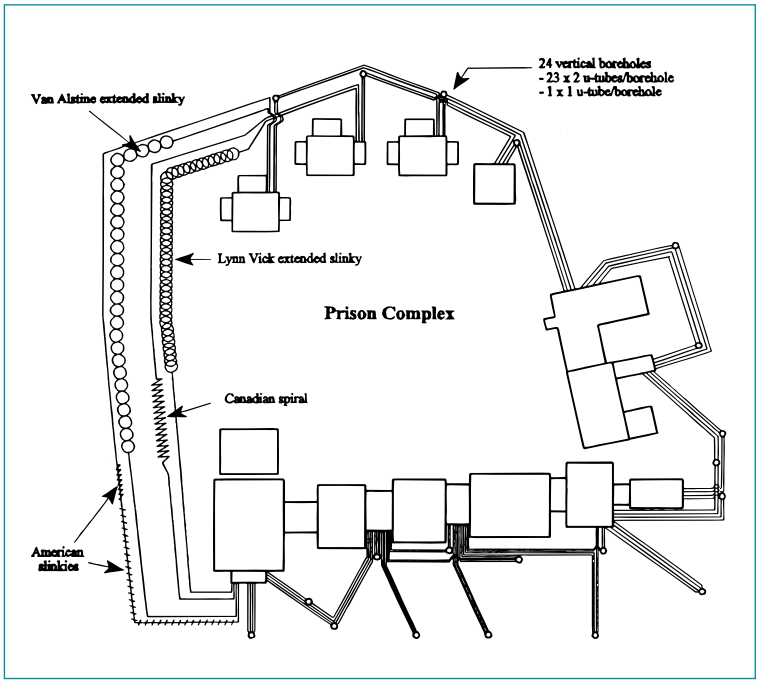

FIGURE 2 Site Plan

Project Costs

The total cost of the HVAC system, including ground coupling, water-to-water heat pumps, solar hot water system, service water heaters (which provide supplemental heat), and cooling coils was approximately $247,600 (Canadian), as shown in Table 1. The ground heat exchanger costs were obtained from Correctional Service Canada, and the remaining costs were estimated from the mechanical drawings and the Means' *Mechanical Cost Data*. A conventional floor radiant system with propane boilers and split system air conditioners for the entire complex was estimated to

TABLE 1 Federally Sentenced Women's Facility—Capital Costs

	ESTIMATED GSHP SYSTEM COSTS	ESTIMATED CONVENTIONAL SYSTEM* COSTS
Water-to-Water Heat Pumps	50,200	–
Ground Heat Exchanger	115,000	–
Circulation Pumps	3,600	–
Storage and Expansion Tanks	11,600	9,400
Solar Heating System	10,800	–
High-Efficiency Boilers	26,300	52,600
Split System A/Cs	–	103,000
Heat Exchangers	22,500	–
Cooling Coils	7,600	–
Cooling Tower for Refrigeration	–	5,000
Total	$247,600 (Cdn.)+	$170,000 (Cdn.)

* High-efficiency propane boilers and split system air conditioning.
\+ At the completion of this report, the $Cdn. was approximately $0.72 US.

A single heat pump with buffer and heating tanks.

cost $170,000, based on cost estimates from the Means' *Mechanical Cost Data*. The incremental cost of the ground-source heat pump system was $77,600.

Operating Difficulties

There were minor installation problems with the heat pump system that consisted of errors in the EMS control program and the control valves for the radiant floor heating.

Very few difficulties were experienced with the GSHP system once the initial start-up problems were corrected. Two compressors and a starting capacitor required replacement. A preventive maintenance program is being carried out by on-site personnel and contractors.

TABLE 2 Federally Sentenced Women's Facility—Annual Energy Performance

	GSHP SYSTEM ACTUAL	CONVENTIONAL SYSTEM* ESTIMATED
Total Building		
Peak Demand (kW)	122	N/A
Electricity (kWh)	460,000	368,400
Propane (therm)	3,823	17,730
Energy Cost ($Cdn)	42,080	50,420
HVAC System		
Peak Demand (kW)	N/A	N/A
Heat Pumps/Spit System A/C (kWh)	102,600	11,000
Circulating Pumps (kWh)	21,800	–
Propane (therm)	2,530	16,430
Energy Cost ($Cdn)	13,085	19,632
Averaged Unit Energy Costs+		
Electricity	$0.082/kWh	$0.082/kWh
Propane	$1.14/therm	$1.14/therm

* High-efficiency propane boilers and split system air conditioning.
\+ Equal to all demand and energy charges divided by metered energy.

System Performance

A detailed monitoring system at the Truro facility monitors the energy consumption of the HVAC system and the effectiveness of the various ground heat exchangers. At the time this case study was being prepared, however, data from the site had yet to be collected. The energy consumption for the facility was obtained from electricity and propane utility bills.

The energy consumption of the heat pump system and the conventional HVAC system was obtained from an energy/environmental analysis performed before the heat pump system was constructed.

Table 2 compares the annual energy performance of the GSHP system with that of a conventional system with high-efficiency boilers and split-system air conditioning.

The GSHP system provides $8,340 savings in annual energy costs. The simple payback period of the Truro Federally Sentenced Women's Facility is approximately 9.0 years.

Building Summary

Building Description

OCCUPANCY: Institutional Complex

LOCATION: Truro, Nova Scotia

GROSS FLOOR AREA: 41,300 ft²

NUMBER OF STORIES: 1

TYPE OF BUILDING CONSTRUCTION: New

COMPLETION DATE: 1994

DEGREE-DAYS:

- Cooling (50ºF): 1,295
- Heating (65ºF): 8,596

Ground-Source Description

OVERBURDEN DEPTH: 52 ft

OVERBURDEN MATERIAL: Clay and gravel

BEDROCK MATERIAL: Sandstone and siltstone

MEAN ANNUAL GROUND TEMPERATURE: 46°F

Energy Consumption and Peak Demand

ANNUAL ELECTRICAL USE — BUILDING: 11.3 kWh/ft²

ANNUAL PROPANE USE — BUILDING: 2.7 ekWh/ft²

ANNUAL ELECTRICAL USE FOR HP SYSTEM: 3.0 kWh/ft²

PEAK ELECTRIC DEMAND FOR BUILDING: 122 kW (winter), 79 kW (summer)

PEAK ELECTRIC DEMAND FOR HVAC SYSTEM: N/A

Interior System

TOTAL INSTALLED HEAT PUMP CAPACITY: 60 tons

NUMBER OF HEAT PUMPS: 20 water-to-water—3 tons each

GEOTHERMAL INTERNAL DISTRIBUTION SYSTEM: HPs in series with boreholes

FLOW RATE/INSTALLED CAPACITY: 0.4 gpm/ton

INSTALLED PUMP SIZES: 2 x 1 1/2 hp

OPERATING PUMP SIZE: 0.05 hp/ton

ADDITIONAL SYSTEMS AND FEATURES:

- Heat exchanger fluid is used to provide free cooling during summer.
- Solar water heaters preheat service water and provide heat to ground loop.
- Waste heat from refrigeration system rejected by ground loop.
- HRVs used to preheat outdoor air.

Type of Ground-Source System

Mixed closed loop (vertical, slinky, and spiral)
24 boreholes, 72 to 289 ft (two U-tubes per borehole)
650 ft horizontal trench (slinky and spiral)

TOTAL HEAT EXCHANGER LENGTH: 4,950 ft borehole (vertical), 650 ft trench (horizontal)

VERTICAL BOREHOLE LENGTH PER TON: 91.5 ft/ton (54 tons) Horizontal trench length per ton: 107 ft/ton (6 tons)

HEAT EXCHANGER PIPE: 1 1/4 in. HD polyethylene

SECONDARY HEAT TRANSFER FLUID: Water

FLOW RATE THROUGH GROUND-LOOP: 24 gpm

Economic Analysis

BUILDING HVAC CAPITAL COSTS: $247,600

ANNUAL BUILDING ENERGY COSTS: $42,080 ($1.02/ft²)

CONVENTIONAL HVAC CAPITAL COSTS: $170,000

CONVENTIONAL ENERGY COSTS: $50,420 ($1.22/ft²)

COST OF GROUND COUPLING:

- $18.18 /ft borehole
- $38.46 /ft trench

ESTIMATED SIMPLE PAYBACK PERIOD OF GSHP SYSTEM OVER CONVENTIONAL: 9.3 years

UTILITY/GOVERNMENT INCENTIVE: Utility provided money for monitoring of system

Owner Satisfaction

Correctional Service Canada is very satisfied with the ground-source heat pump system. The department feels that the GSHP system has been effective at meeting its CO_2 reduction targets.

Multiple heat pumps with domestic hot water preheat tank.

References

1. *Means mechanical cost data, 1996, 19th annual edition*. 1995. Kingston, Mass.: R.S. Means Company, Inc.

2. O'Blenes, B. 1994. *Closed-loop heat exchanger comparison and system monitoring proposal—Federally-Sentenced Women's Facility, Truro, Nova Scotia*. Correctional Service Canada.

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 Cat. No. M92-166/1999E ISBN 0-662-27858-5
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