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Truro Facility for Federally Sentenced Women

Vertical Borehole Groundloop Heat Pump Installation

Truro, Nova Scotia, Canada

Using Earth Energy

Reducing anthropogenic emissions such as $CO_2$by about half over the next few decades is the order of change needed to cap global warming at current levels. To achieve this, Canadian and American CO_2 emissions, which are now about 5 tonnes CO_2 /person/year, would have to be reduced by a factor of roughly 10 to about 0.5 tonnes/person/year. Doing so, and demonstrating to many populous countries that are now undergoing rapid economic development how this can be done, is crucial to the planet's long term survival.

Earth energy heat pumping is a partially solar energy technology that is becoming ever more economically viable. It can become a crucial component of a cost-effective global strategy for reducing not only CO2 emissions that cause global warming, but also NO_x and SO_x emissions that cause acid rain and smog, and CFC / HCFC emissions that cause depletion of stratospheric ozone. However, problems remain. Unless earth energy is combined with other integrated technologies such as cogeneration, its net economic and environmental benefits relative to utility electricity are marginal where natural gas is available and inexpensive. Further, the North American engineering consulting community in general is still not comfortable designing buildings that incorporate earth energy systems and often produces designs that are unnecessarily expensive. Nonetheless, Canadians have become world leaders in developing this technology and are now starting to demonstrate its cost and environmental effectiveness in a variety of state-of-the-art applications, a few of which are outlined in this paper.

Earth energy and the environment

Our ultimate energy source is the sun. Oil, gas, coal, bioenergy, wind and hydro (through the hydrological cycle) are all derived from solar energy. Capturing solar energy directly is expensive and difficult because of its diffuse and erratic nature, but nature has provided a clean, cost-effective solution. Because the earth is so massive, nearly half of the solar energy that reaches the earth is absorbed and stored in the geomass. The ground remains at a relatively constant temperature all year, providing a higher temperature source than outdoor air in the heating season, and a lower temperature than air for cooling in the summer. One can even freeze the earth in winter, collect and use the latent heat, then use this ice stored in the ground as the sink for very efficient cooling. By fall, the ice has melted and the ground has heated. This thermal storage is then used to further increase the efficiency of the earth energy heat pump.

Compared with air-source heat pumps and air conditioners, earth energy heat pumps result in far higher thermodynamic efficiency. Also, while air-source units cannot operate in Canada's extreme winter temperatures, little or no supplemental electric resistance heat is required with earth energy systems. Moreover, by using well known and proven heat pump technology, it is relatively easy and environmentally responsible to heat and cool buildings by using the stable temperature of the earth as a heat source, a sink and a storage medium. Earth energy heat pumping systems use non-polluting renewable solar energy stored in the ground, upgrade it using sealed HCFC (or HFC or other) heat pumping equipment that emits essentially no environmentally damaging effluents or emissions, and transfer it to buildings. Even when the electricity used to run the pumps, fans and compressors is generated from fossil fuels, the heat energy delivered to points of use is in the ratio of more than two non-polluting stored solar energy units to each unit of electricity.

Northern countries like Canada and the northern U.S. are especially well located to exploit the full economic benefit of earth energy technology all year long because the need for both heating and cooling matches the seasonal capabilities of the technology more closely than in more southerly locations. Earth energy systems that meet CSA C446/ARI performance standards save more than 60% in heating ($1,000 / year in most homes), and 25% in cooling ($100 / year) when compared to conventional electrical alternatives. Based on conservative Ontario Hydro figures of 6.1 kW savings per unit, Canada already uses this technology to save more than 200 MW of capacity annually, and the U.S. saves more than 1,000 MW. By expanding the use of earth energy systems, the polluting emissions caused by the generation of electricity from fossil fuels in North America could be reduced by over three million tons of CO_2 annually.

An Architect's Preliminary Sketch of FSW, Truro

Types of Earth Energy Heat Pumping Systems

There are two principal types of earth energy systems. The most common is the **open loop ground water system**, in which water is extracted from and returned to an aquifer or surface water. The alternative is a **closed loop system** using pipe heat exchangers that are buried horizontally or vertically in the ground, in which circulate antifreeze or refrigerant (direct expansion systems). These closed loops can be installed almost anywhere, but are usually more expensive to install.

Through its **Energy Efficiency Act**, Canada has proclaimed some of the most stringent performance requirements for earth energy heat pumps in the world. The minimum efficiency allowed for well water systems is 310%, rated to CSA / C446 Coefficient of Performance (COP) of 3.1 at 10°C entering water, and 280% (C446 COP of 2.8 at 0°C entering liquid). This increased efficiency reduces electricity use, which means lower electric bills for the consumer and lower demand for and pollution from the utility

Main Entrance Building off James St., Truro, N.S.

Correctional Services Canada Facilities

The **Correctional Service, Canada** (CSC) operates over 40 penitentiaries, has parole offices in most municipalities, and various other facilities such as half-way houses, staff colleges, and regional and national headquarters complexes. It is the fourth largest custodian of Federal Government property, after Defence, Transport, and Public Works.

The CSC is reducing its global warming emissions by following two main strategies: reducing CO_2 emissions caused by fossil fuel combustion attributed to the CSC, and managing the decomposition of putricible materials. The latter category includes materials such as garbage, yard and agricultural wastes, sewage sludges, and manures dumped in landfills or spread on CSC farmlands to minimize emissions. A variety of aerobic composting technologies are used to reduce global warming emissions by the equivalent of 0.3 tonnes CO_2 per year per tonne of decomposable waste, but are not discussed here.

Combusting the fossil fuels attributed to the CSC's penitentiary operations causes over 17 tonnes of CO_2 emissions per "occupant" per year. (Occupancy = inmate count + 1/3 of staff). Emission quantities are calculated by converting the quantities of fuel purchased from cubic volume units to input energy quantities expressed in megajoules, then multiplying the input megajoules by the values in **Table 1.**

Table 1. Unit CO2 Emissions for Various Fuels

Fuel Type	Grams CO2 per input megajoule
Natural Gas	50
Propane	60

The figure of 255 g CO_2 /mj for utility electricity was derived using these assumptions:

1. Of the input energy used at a coal-fired electricity

Propane	68
Furnace Oil #2	73
Coal	85
Utility electricity	255

generation plant about 1/3 is available as electricity at a CSC facility, and 3*85 g/mj = 255 g/mj. The remaining 2/3 is wasted, but is attributed to the CSC facility using the electricity.

2. All electricity purchased by the CSC is deemed to have been coal-generated, even though many Canadian utilities generate electricity using hydro or nuclear power. The rationale for this is complex but interesting. Put simply, peat bogs in northern Canada are thought to be as crucial as rain forests in global carbon recycling. Flooding bogs for hydrc-electric dams alters their biochemistry so that methane is produced to an extent that as much global warming is caused per megajoule of electricity as would have been caused by a coal-fired plant. Reducing the electricity purchased by the CSC will eventually reduce generation of coal-fired electricity or its equivalent somewhere in the energy system.

Detached Visitation House + 2 Residences

One of the major strategies used by the CSC to reduce CO_2 emissions is to use ground source heat pumping and other solar technologies where practical. Earth energy systems also require fewer roof-mounted and other building appendages, a benefit in the high-security, vandalism-prone prison environment. Installing gas-fired cogeneration and low-temperature district heating technology is practical, especially where it can be coupled with earth energy heat pumping. It should be noted that the term cogeneration as used here means generating electricity using a reciprocating natural gas engine and using most of the waste heat from the exhaust, engine coolant, and turbocharger. However, coupling an engine mechanically to an earth energy heat pump while injecting waste heat into the ground source loop also is cogeneration.

Another element of the CSC strategy is to use natural gas energy in preference to any other fossil fuel or utility electricity, and to use propane where natural gas is not available. Migrating toward a natural gas infrastructure strategically positions the CSC to eventually use biogas, which can be produced on an environmentally sustainable basis.

Finally, the CSC is minimizing the need for purchased energy in buildings by adopting most R2000 and C2000 conservation practices for constructing and renovating buildings.

4 Pipe Vertical Tubing Sets Pressure tested and Waiting for Installation

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Federally Sentenced Women Facility, Truro, Nova Scotia

The concepts and principle described above have been applied in the Facility for Federally Sentenced Women, a very small prison in Truro, Nova Scotia, which is now under construction. The architectural and engineering design consultants were asked to design the facility to achieve a total energy use level of 1300 MJ/m^2 / year (or 361 kWh/m^2 / year), about 1/3 of the energy used in traditional CSC facilities. This energy use budget includes purchased electricity, calculated at 3 times the meter reading). It was known that the target could not be met without applying an advanced energy technology such as cogeneration and / or earth energy and / or solar energy, but the construction budget was not augmented to provide extra money to meet this target.

The resulting architectural design closely followed the **Advanced House** and **C2000 Commercial program** technical guidelines for energy and environmental efficiency.

Two principal alternatives were considered for heating and cooling:

1. Earth energy heat pumping using a conservative CoP of 3.1.
2. Propane gas appliances with air-cooled R22 air conditioning.

The analyses of these two options is presented in Table 2 and Table 3.

Table 2 - Earth Energy Heat Pumping, CSC Truro		
Electricity Use	128,243 kwh/year	Cost @ $ .077/kwh
CO_2 from Electricity	128,243 kwh/year *3.60 MJ/kwh *85 grams CO_2/MJ coal *3 waste heat MJ/MJ input *.001 kilograms/gram = 117,727 kg CO_2 / year	
Effect of increasing COP from 3.1 to 3.7	117,727kg CO_2 /year / 1.20 ratio COP/old COP = 98,106 kg CO_2 / year	

From an environmental standpoint, the earth energy option using a COP of 3.1 appeared to be slightly less

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desirable than the conventional option. However:

1. The COP estimate of 3.1 was conservative, based on assuming rather low groundwater temperatures of 0°C in the spring and 8°C in the fall.
2. The calculation that the earth energy option would use 128,243 kWh hours / year did not include an allowance for the heat to be captured from the institution's refrigerators and freezers, estimated as another 5% COP improvement.
3. Experiments carried out by the University of Moncton for the CSC, and using their new refrigerant blends for replacing R22, indicated that CoP could be increased by 15%. This was also left out of the CoP calculations used.

Thus, a Cop of 3.7 is considered to be achievable.

Table 3 - Propane Heat with R22 air Conditioning, CSC Truro		
CO_2 from Propane:	56,224 litres / year *27.1 MJ heat/litre *60 grams CO_2 / MJ *.001 kilograms / gram = 91,420 kg CO_2 / year	Cost @ $ .256/litre =$ 14,393 / year
CO_2 from electricity	11,020 kw *3.60 MJ/kwh *85 grams CO_2/MJ coal *3 waste heat MJ/MJ input *.001 kilograms/gram =10,116 CO_2 /year	Cost @ $ .077/kwh
Total CO_2 for this option	91,420 kg CO_2 /year from electricity + 10,116 kg CO_2 /year from propane = 101,537 kg CO_2 /year	

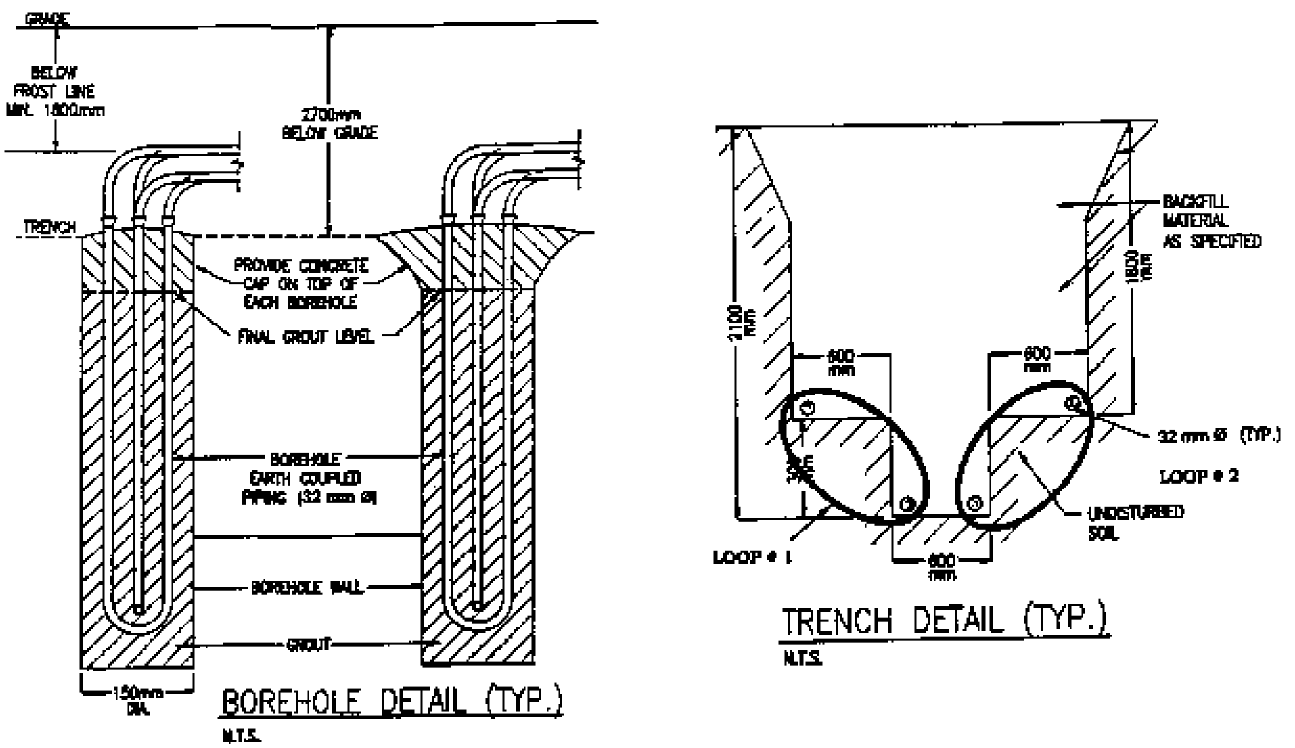
The earth energy option allows adding low-grade heat from solar sources and/or cogeneration. The consultants indicated that either solar collection or propane-fired cogeneration would be prohibitively expensive to install initially. Nevertheless, the earth energy option strategically positioned the CSC to add this capability later, and provision was made to do this. (In fact, solar was added as construction was being done.)

The consultant's calculations indicated that the facility would not meet the design specification for 1300 MJ/m^2 annual energy use with either of these options, but came closest with the earth energy heat pump option (Table1) (1). It could be improved later by the addition of a small cogeneration engine. In view of these advantages and its lower annual operating costs, this option was chosen.

American & Canadian "Slinky" style Horizontal Geothermal Tubing

The specification for multi-capacity liquid-to-liquid heat pumps was so stringent that the winning manufacturer, **NORDIC® of New Brunswick**, had to develop a whole new line of three-speed, two compressor, brazed plate exchanger high efficiency units.

Another significant feature of this facility is that it uses four one-ton test loops to verify the relative installation costs and performance of the **SVEC spiral** (developed by the National Research Council) and three variations of the **SLINKY** (developed by the International Ground Source Heat Pump Association).



Borehole and Horizontal Trench Configurations

Earth Energy and Cogeneration

A key management issue is to make CSC facilities cost-effective while implementing measures to improve environmental performance. This challenge is complicated in Canada by the fact that, where natural gas is available, the cost of a megajoule (MJ) of gas energy is typically less than one-fifth of the cost of a megajoule of electricity.

The 5:1 ratio makes it hard to justify electrically-powered earth energy heat pumping on economic grounds, where an alternative of a natural gas boiler is available. If heat pumping is done with a COP of 3.5, the 0.286MJ of electricity used to produce a MJ of heat from earth energy would still cost 14% more than the heat would have cost if generated in an 80% efficient gas appliance. Further, the gas appliance would create only 62.5 grams CO_2 per MJ of heat, whereas purchased electricity for the heat pump would produce 72.9 grams.

However, **where natural gas is not available, ground source heat pumping can be environmentally preferable** to combustion heating using any other fossil fuel, even propane. It may also be more cost effective, as in the Truro prison facility.

The 5:1 ratio works well for reciprocating cogeneration engines fired by natural gas. In this case the cost of the gas needed to cogenerate electricity at 30% efficiency is only 2/3 the price of electricity, and 50% of the input energy is available as “free” heat. Further, natural gas-fired cogeneration causes only 167 grams CO_2 per MJ electricity, as compared with the 258 grams CO_2 produced at a coal-fired electricity plant. Finally, when utility electricity is purchased, the 1.67 MJ of "free" heat per MJ of cogenerated electricity has to be replaced by burning 2.08 MJ gas in an 80% efficient appliance, causing 104 grams CO_2 to be emitted.

CSC studies indicate that, in a typical load displacement cogeneration installation of 500 kw at a large 500 occupant penitentiary, capital costs of about $1 million will save over $150k annually, and will reduce societal CO_2 emissions by 2500 tonnes/year, NO_x by 10 tonnes/year, and SO_x by 25 tonnes / year. It is unusual for any other technology to allow redudng CO_2 emissions 5 tonnes/occupant/year.

In view of these factors, where low cost natural gas is available, a viable way to take advantage of the environmental benefits of earth energy technology is to couple it with cogeneration. This is demonstrated with the Muskoka Institution.

Muskoka Medium Security Institution, Beaver Creek, Ontario

This will be a relatively large penitentiary, to be built to accommodate about 600 occupants, and to be located in an environmentally sensitive area of Ontario's vacationland. It was in the early design stages in January 1995.

Natural gas will be available at the facility for about 20% of the cost per MJ of electricity from Ontario Hydro. Bringing in a 44 KV power line with associated equipment was estimated to cost about $1 million. Hence this was an excellent opportunity to examine the possibility of using earth energy to enhance the environmental benefits and cost-effectiveness of cogeneration. Accordingly, the following is one of the scenarios for the Institution's energy systems that the design consultants were asked to evaluate:

1. The facility would not be serviced by an electrical utility but would instead be equipped with three 700 kw cogeneration equipment packages. An early guess was that the peak electrical load of the institution would be under 2 megawatts. The emergency power requirement would be about 0.5 megawatts in summer and up to 1.4 megawatts on the coldest day of winter.
2. The cogeneration installation's waste heat would be used to indirectly heat domestic hot water. Insulated plastic and steel piping would distribute hot water at 55°C to all buildings. The hot water would pass through heat exchangers in the Domestic Hot Water (DHW) tank(s) in each building.
3. The DHW tank(s) in each building would supply DHW and heat to the building's heating system. When the cogenerated heat was inadequate for both DHW and space heat in a building, it would be supplemented by earth energy heat pumps.

The combined peak winter heating and DHW load would be about 5 megawatts. However, only 3.2 megawatts of input gas would be required to generate 1.0 megawatt of electricity and 1.6 megawatts of cogeneration heat. The 1.0 megawatts of electricity would drive heat pumps with a COP of 3.5 to produce 3.4 megawatts of heat. The cogenerated heat would simultaneously add 1.6 megawatts of heat to the DHW system.

Emissions causing global warming associated with space and DHW heating for this configuration would be about half those that would be generated by gas-fired boilers. (About 155 MJ would be delivered per 100 MJ gas input. An 80% efficient gas system would deliver about 80 MJ per 100 MJ gas input.)

Performance Monitoring

One of the important features of the CSC Truro facility is extensive and reliable monitoring. The heat pump systems will be instrumented and monitored for the following performance parameters:

1. Operating power draws and times for units and independent pumps.
2. Air temperatures and flows.
3. Liquid temperatures and flows.
4. Ground temperatures at coils and out to 2 meters.
5. Operating and maintenance costs for individual units and systems.

When data are available, they will be used to verify the energy simulation models (such as Hot2000) that were used for the analyses. They will also verify new industrial installation designs, practices and performance. All in all, the monitoring should have real value and impact.

Conclusions

Earth energy heat pumping could become a crucial component of a cost-effective national strategy for reducing $C0_2$ and other polluting emissions associated with burning fossil fuels. Where cheap natural gas is not available, earth energy technology can confer enormous environmental benefits and be very cost-effective. Where cheap natural gas is available and inexpensive relative to utility electricity the environmental and economic benefits of earth energy are marginal. However, environmental and cost advantages can be achieved when earth energy technology is used, often in combination with other integrated technologies such as cogeneration.

For success in tomorrow's residential and commercial institutional HVAC marketplace, the next generation of heat pump technology must meet demands for:

1. Environmental emission management benefits.
2. Better indoor environment (comfort and IAQ).
3. Personal control and security.
4. Reduced utility peak load demands.
5. Performance throughout buildings' life cycles.
6. Environmental (production, use, disposal).
7. Renovation and retrofit demands.
8. Better capital and operating cost-effectiveness.

The CSC Truro project has helped to prove that next-generation Canadian earth energy heat pump technology is more than capable of meeting the challenges.

Authors:

C. S. L. McNeil, P.Eng. Earth Energy Advisor CANMET, NRCan

TK. Crawford, PEng. Special Advisor - Environment Correctional Services, Canada

B. Eggertson - Executive Director - Canadian Earth Energy Association

Architects:

Sperry & Partners Ltd., Dartmouth, Nova Scotia; Mitchell Brooks, Design Architect

Mechanical Consuftants:

Enerplan Consultants Ltd., Halifax, Nova Scotia; Scott Moore, Design Engineer

General Contractor:

L & R Construction Ltd., Stewiacke, Nova Scotia

Heat Pump suppiler:

Maritime Geothermal Ltd., Petitcodiac, New Brunswick

Project Manager:

PWGSC, Atlantic Region

Owner:

Correctional Services of Canada