RESULT 299

CADDET energy efficiency

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Energy-efficient HVAC in museum building

Geothermal heating and cooling for Montreal's Biosphere

Summary

Montreal's Biosphere is a unique interactive museum aiming to raise awareness of the Saint-Lawrence river and the Great Lakes ecosystem. Due to its specific architecture, energy consumption is substantial. The combination of a geothermal system and leading-edge technologies produces an impressive energy efficiency. Compared to a conventional electrical option, the geothermal system shows a reduction in energy usage of 459 MWh (approx. 21%) annually, which is significant considering the extensive use of windows throughout the building and Canada's northern climate. The payback period is just under six months.

Highlights

- **Total peak capacity: heating 360 kW; cooling 610 kW**
- **Annual electricity savings of 459 MWh**
- **Simple payback period of 0.4 years**

Montreal's Biosphere, located on Saint-Hélène's Island.

Aim of the Project

One of the highlights of Montreal's Expo '67 was the United States pavilion. This geodesic dome, 76 m (250 feet) in diameter and 63 m (206 feet) high, was in 1995 transformed into a museum to promote awareness of the Saint-Lawrence river and the Great Lakes ecosystem.

Preliminary study showed natural gas to be the most economical system for heating and cooling the building. However, this proposal was rejected because of the owner's requirements to respect the environment and to utilise a system following the same guidelines as the Biosphere. The solution retained involved a geothermal system using electricity as its only energy source. The energy consumption costs of the geothermal system are similar to those of the natural gas option, while still meeting the environmental criteria.

The Principle

In order to respect environmental and energy-efficiency criteria, engineers specified a geothermal heating and cooling system. A geothermal system uses the consistent temperature of the ground, or an underground source, where conventional systems use boilers, chillers, and cooling towers. In the Biosphere, a semi-open loop hydrothermal system was installed. The main system features comprise:

- the use of submersible pumps sunk 91 meters (300 feet) below ground level to carry water from an underground source to two plate heat exchangers;
- the transfer of ground-water heat to a semi-open loop through heat exchangers before rejecting it back into the earth through an injection well;
- the use of plate heat exchangers rejecting heat into the water loop, depending on heating or cooling needs in each room of the museum.

The Situation

The interactive museum has a surface area of 4,500 m^2 (48,700 ft^2). Windows make up more than 40% of the new building, a natural fit for a unique environment and an expression of its role. Designing the air-conditioning and heating systems was a challenge since more than 80% of the total area is considered a peripheral zone, thus increasing energy consumption.

Because of the proximity of the Saint-Lawrence river, surface water might have been used as a source for the geothermal system. This option was rejected because the membrane installed in 1967 to protect the island from natural erosion could not be tapped without involving major work. Even without the membrane, marine creatures (e.g. zebra mussels) would sooner or later clog the water intake. Fortunately, testing showed an underground water source capable of providing enough energy to meet the needs of the building, which are 610 kW (175 tons) in cooling capacity and 360 kW (1.23 Btu/h) in heating capacity.

The geothermal system consists of two submersible pumps sunk 91 m (300 ft) below ground level to carry a total flow of 22.1 l/s (350 gal/min) of water from an underground source at a constant temperature of 9°C (48°F) to two plate heat exchangers. The heat from the underground water is transferred to the heat exchangers before the water returns to the ground via two injection wells (creating a semi-open loop).

Climate was a very particular concern for a geothermal application. Temperature maxima of 31°C (88°F) and minima of -26°C (-16°F) are typical. Freezing was a major consideration, especially in wintertime when the thermal loop has a low supply temperature (around 4.5°C) and no anti-freeze is used considering the environmental criteria. A high-density rigid insulation was installed four feet deep to protect the underground hydrothermal piping from freezing.

Production- and injection-well materials have been selected to meet strict corrosion- and wear-resistance standards. The production well is made of galvanised steel piping (capable of sustaining a submersible pump and piping 91 m (300 ft) below ground level). Temperature, pressure, well-level, and flow-meter sensors are installed in the hydrothermal loop. Well-level sensors are all monitored by the centralised energy management and control system (EMCS) to anticipate any plugging in the two return wells and/or a decrease in the production well's water level.

The plate heat exchanger forms a barrier and eliminates any risks of contamination caused by

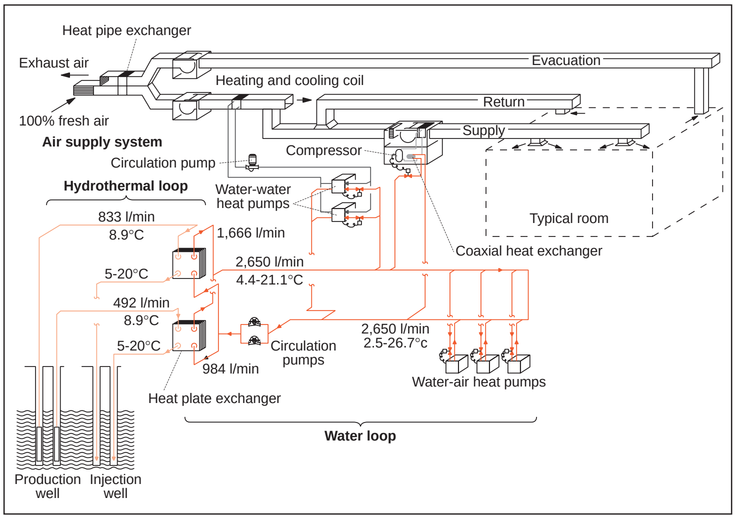

Figure 1: Operating diagram of the geothermal system showing the water- and hydrothermal loops.

suspended particles in the underground water source and by the potential seepage of contaminated water from heat pumps into the injection wells. Due to the low average return temperature of 2.5°C (36°F), extended-range heat pumps are used for their low-temperature performance capacity, eliminating possible freezing risks at the coaxial heat exchanger in the heat pumps. Two water-hammer arresters and one soft-start starter have been added to each loop to eliminate any possible problems. Figure 1 shows the operating diagram of the geothermal system.

The design paid special attention to comfort and air quality, despite no specific indoor conditions for the exhibits. A fresh air flow of 5.5 l/s (11.6 ft^3/min) is generated by two constant volume independent systems for an average 12.1 l/s per person (25.7 ft^3/min per person). The fresh air system is directly connected to the return air duct of each heat pump to make sure that the right quantity is delivered into the room.

The building's total annual energy consumption amounts to 1,757 MWh, a saving of 21% over a conventional electrical option.

The Organisation

The Biosphere is an interactive museum to promote awareness of the Saint-Lawrence river and the Great Lakes ecosystem. The museum accommodates around 300,000 visitors per year. The museum is owned by the city of Montreal and managed by Environment Canada.

Table 1: Estimated investment cost and payback period.

Energy source	Estimated investment cost (CAD)	Annual energy cost (CAD)[2]	Energy cost (CAD/m^2)	Simple payback period (years)
Geothermal	525,000	124,155	0.24	0.41
Electrical	508,375[1]	164,330	0.31	–
Natural gas	532,600	109,426	0.21	0.44

[1]Including the cost of a new transformer for the new electrical supply.
[2]From Table 2.

Table 2: Annual building energy consumption for various energy sources.

Category	Geothermal system	Electrical system[1]	Natural gas system[2]	Difference Geo./N.G.
Heating (kWh_e)	214,775	676,043	880,676[3]	(665,901)
Fresh air heating (kWh_e)	124,424	391,650	587,118[3]	(462,694)
Cooling and fresh pre-cooling (kWh)	198,196	136,000	136,000	62,196
Lighting (kWh)	647,884	647,884	647,884	
Domestic hot water (kWh)	12,321	12,321	12,321	
Motor fan and equipment, winter (kWh)	261,785	94,900	155,266	106,519
Motor fan and equipment, summer (kWh)	126,979	86,404	86,404	40,575
Humidification (kWh)	170,612	170,612	170,612	
Total (kWh_e)	1,756,976	2,215,814	2,676,281	(919,305)
Maximum demand (kW)	393	805	266	127
Annual energy cost (CAD)	124,155	164,330	109,426[4]	14,729

[1]The electrical system uses an electrical chiller and boiler, cooling tower, and hot water loop.
[2]The natural gas option is similar to the electrical system except for the boiler.
[3]141,953 m^2 (5,012,465 ft^2) of natural gas for heating and fresh air in total.
[4]CAD 82,700 of electricity and CAD 26,726 of natural gas.

Economics

While the geothermal method already offers an excellent energy efficiency, other energy-saving measures were used to improve this even further. These measures include energy-efficient lighting, high-efficiency motors, high-performance heat pumps, and fresh air preheated or pre-cooled by a heat exchanger. Also for optimum operation, the EMCS was used to reset temperatures during non-occupied periods, load rejection, etc.

The energy costs may seem relatively high compared to similarly used buildings, but fall within a reasonable range considering the building's particular architecture (40% of window area and 80% of peripheral zone) and the fresh air quantity (12.1 l/second/person; 25.7 ft^3/min./person). The usual design criteria exclude the environmental side most of the time. Normally, a natural gas option would have been the retained solution, but was rejected because of the added environmental requirements.

Tables 1 and 2 show the estimated investment cost and payback period plus the annual building energy consumption for different energy sources, respectively.

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* IEA: International Energy Agency
OECD: Organisation for Economic Co-operation and Development

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 co-operation 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.