Ground Source Heat Pumps

Scott Maynard

Agriculture and Agri-Food Canada, #420, 4321 Still Creek Dr, Burnaby, BC V5C 6S7
Email: maynards@agr.gc.ca

▪ Introduction

Ground source heat pump technology has been in existence for over 20 years. It harnesses the stable temperatures of the earth to provide a renewable source of heating and cooling throughout the year at substantially lower life cycle costs than conventional building heating and cooling systems.

▪ Principles of Ground Source Heat Pumps

During the heating season, liquid (ground water or a glycol mixture) passes through a ground loop absorbing heat from the earth. It then flows through a heat exchanger within the heat pump where heat is extracted from the warmed fluid. The liquid is then pumped back to the ground loop to absorb more heat.

The heat exchanger transfers this heat through a refrigeration process in a liquid refrigerant which boils absorbing heat as it changes to a gaseous phase. The gas then flows to a compressor, which increases the pressure of the gas and reduces its volume forcing it back into a liquid phase and increasing its temperature. The hot liquid flows into a condenser coil from which heat is transferred to either a stream of air flowing over the coil or a hydronic heating fluid flowing through a hot water circulation system to provide building heat. The refrigerant then passes through an expansion valve where the temperature and pressure drop off and the refrigerant returns back to the heat exchanger where the cycle begins again.

During the cooling season, the direction of the refrigerant flow is reversed by a valve. The heat pump refrigerant picks up building heat and transfers it to the heat exchanger back to the ground water or glycol mixture to the earth.

▪ Ground Source Heat Pump Systems

There are several types of ground source heat pump systems. The most common systems include:

Open Loop

Submersible pumps are installed in wells or aquifer. Groundwater is pumped through a heat exchanger and then to a heat pump. The groundwater is then returned back to an injection well. Pumping and injection wells must be separated by a predetermined distance to avoid thermal breakthrough between the two wells. The heat pump can extract energy from the water to either heat or cool the building. In some cases if the groundwater is sufficiently cold enough, (10^oC) the ground water alone could provide free cooling to a building. The low installation costs of the direct cooling systems tend to be one of the least expensive compared to other systems.

Open Horizontal Loop

This is a closed pipe loop system, which is installed at a shallow depth underground (>1.2m). A fluid is circulated through the pipe loop and exchanges energy from the ground to the fluid, which then is used by the heat pump. Depending on the building load, this system may require a large land area.

Closed Vertical Loop

Vertical U tubes are installed in bore holes that are drilled through the earth to a specified depth which are then sealed. Similar to the horizontal loop system, fluid is circulated through the vertical loop, which is then used by the heat pump. This method requires less land but is the most expensive due to drilling costs.

▪ Ground Source Heat Pump Performance

The heating efficiency of ground source heat pumps is defined by the coefficient of performance (COP). This can be determined from the amount of thermal energy produced divided by the amount of electrical energy consumed. Typical heat pump COPs range from 3.5 – 4.0. Accordingly, for every kW of electrical energy consumed provides 3.5 – 4.0 kW of heat.

Consider a building in which a boiler operating at 85% efficiency requires 1000 MBTU/hr of natural gas at peak load to maintain a controlled internal temperature. At peak load, the boiler will consume approximately 11 GJ of natural gas per hour, which at a gas cost of $1.16/GJ will cost $11.60/hr to operate. Since the boiler operates at 85% efficiency, the actual heat produced is 9.35 GJ/hr or 249 kW. A heat pump with a COP of 4 would only consume 62.3 kW of electrical energy to produce the same 249kW heat output. At an electrical energy cost of $0.05/kWh the heat pump would cost $3.12/hr to operate. Consequently, the heat pump can provide the same level of heating but at less than one third the cost of the conventional boiler at peak load.

Cooling performance is measure in seasonal energy efficiency ratio or SEER. The SEER is determined from the ratio of cooling capacity in btu/hr divided by the energy consumption in watts. Typically ground source heat pumps operate at SEER > 12. The higher the SEER the greater the efficiency.

Direct groundwater cooling applications can sometimes exceed these SEER ratios. Consider a groundwater open loop system whereby groundwater is pumped from an aquifer at 5^{o}C and is returned at 10^{o}C. One ton of cooling (12,000 BTU/h) would be provided at a pumping rate of 0.21 L/s (3.3 gpm). This type of cooling system is currently being used at a large federal office laboratory facility in Agassiz, B.C. Ground water is pumped at 19 L/s (300 gpm) by a 20 hp submersible pump from one well and is circulated through a heat exchanger within the building. This provides 90 tons of cooling (1,080,000BTU/h). A 20 hp pump at full load requires approximately 22 kW of electrical energy. This is equivalent to a SEER of 49 or 4 times the efficiency of a conventional heat pump.

▪ Agricultural Applications

Dorchester Penitentiary

Corrections Services Canada operates a swine barn at the Dorchester penitentiary in New Brunswick. In 1994, CSC renovated the barn by installing a new in floor heating system in a farrowing room (300 sq.m.), weaner room (180 sq.m.) and staff area (60 sq.m.). The rooms are heated by two 5 ton ground source heat pumps circulating 43^{o}C hot water through the concrete floor. The heat pumps are direct expansion type (DX) to the earth and circulates the refrigerant directly through a series of copper tubes installed in 10 vertical boreholes to a depth of 30.5 m.

After two years of operation, the vertical bore holes collapsed, crimping the copper tubes resulting in a shutdown of the heat pump. The site is located close to the tidal influence of the Bay of Fundy. It is speculated that salt water intrusion from the ocean along with soluble soil conditions has resulted in the structural failure of the formation. CSC has plans to replace the vertical borehole system with a horizontal loop.

There are more than 5000 Ground Source Heat Pump applications in New Brunswick. Of these only a couple of systems have had this kind of failure.

▪ Design Considerations & Field Issues

The selection of the type of system will depend on a number of factors:

Analysis of Heating and Cooling Loads

A proper load analysis must be carried out to determine the size of the ground source heat pump system. The following questions must be considered:

- Will the equipment be used strictly for heating purposes, or for both heating and cooling?
- What are the differences between heating and cooling loads?
- What percentage of the respective loads will be covered?

While the ideal situation would be to have identical heating and cooling loads, this never happens. Most systems are not designed for maximum heating loads as this leads to over sizing of equipment. In fact many designers prefer to design for 75% of the load and then have supplemental equipment for the extremes in weather conditions.

Land Availability

The choice between horizontal loops vs. vertical closed loops depends upon the land available: Horizontal loop systems are less expensive than vertical loop systems but require more land area and more piping.

Site Characterization

Soil conditions will dictate the amount of energy that can be stored in the ground and influence the length of closed loop piping and the type of closed loop system. In an open loop system, groundwater depth will determine pump sizes. Groundwater temperature will determine whether free cooling is an option. Groundwater chemistry will determine if there is a chance of well screens being fouled by manganese or iron bacteria thereby reducing the ability to pump and return ground water back to the aquifer. Ground water transmissivity or speed will also impact an open loop system's ability to store energy into an aquifer formation.

Budget

Any installation with a payback of less than 8 years should seriously be considered

Of course construction and installation costs are always important aspects of any project. In order to arrive at a decision on whether to implement a GSHP system, the owner must properly assess the additional costs over conventional systems. A proper life costing exercise should be carried out to assess engineering and development costs, capital costs, annual operating and maintenance costs, interest carrying costs and energy savings to determine whether reasonable paybacks will be realized. Any installation with a payback of less than 8 years should seriously be considered given the rising rate of oil and natural gas prices.

Natural Resources Canada have developed an electronic decision making tool for assessing the feasibility of ground source heat pumps known as RETscreen. This tool can be downloaded free of charge at the following web site: http://www.retscreen.net/ang/menu.php. Also available free of charge are case studies, a training manual and an e-text book to support the user. The model allows for a project to be quickly assessed for its potential energy savings against the project costs. This model is only a screening tool. If the project shows merit, then the services of qualified professional engineers, hydrogeologists and/or certified GSHP contractors should be engaged.

Field Applications

GSHP systems can be used to provide heating or cooling but are most advantageous where both heating and cooling are required.

In typical modern livestock farms a logical application is to provide year round heating and air conditioning of office and staff areas. On larger farms such applications frequently demand heating capacities of 20 to 30 kW and 3 to 5 tons of cooling. A few systems of this type have been installed but given the number of large livestock operations constructed over the last decade it would seem that insufficient consideration has been given to the potential operating cost savings.

An application within the swine industry that is particularly amenable to GSHP technology is the heating and air conditioning of Artificial Insemination Semen Collection centers, or Boar Studs as they are more commonly known. Most livestock facilities are cooled only with large volumes of ambient air. Typically the cooling side of barn ventilation systems are designed only to keep the facilities one or two degrees below ambient air temperature and depend on the animals to adapt. Mechanical cooling is seldom considered. However in a boar stud the increased value of the superior quality animals, the benefits of cooling on the physiological aspects of semen production and semen quality, and the high added value of the products of semen collection and distribution make mechanical cooling attractive. Thus, the need for both winter heating and summer cooling make this an excellent opportunity for GSHP systems. Typical heating loads in commercial boar studs are 60 to 100 kW with corresponding cooling loads of 25 to 45 tons.

A few boar studs have been constructed using groundwater cooling but it would seem that greater use could be made of GSHP technology.

Conclusion

Ground source heat pump technology has been in existence for years. This technology offers reliable means of reducing operating and maintenance costs as well as reducing greenhouse gas emissions that contribute to global warming.

The decision to ultimately install a ground source heat pump will depend on site conditions, local energy costs, energy loads, the type of application, the availability of qualified professionals, and the commitment of the user. No system is perfect, however with proper research, users should be able to make an informed decision on whether a GSHP system will meet their application needs.