District GeoExchange Systems & Waste Heat Recovery

Ed Lohrenz, B.E.S, CGD
ASHRAE Member

ABSTRACT

Remote communities must import energy to sustain life. Diesel powered generators are often used in small communities not connected to the electrical grid. Heat recovery from the generators can become the nucleus of a district geothermal energy system for a community. Other energy sources in the community can be integrated into a district geothermal system. These sources can include heat recovery from refrigeration plants in ice arenas or grocery stores, solar thermal, process heat, bio-mass boilers, etc.

Waste energy is not always available when it's needed. A ground heat exchanger (GHX) can be used as a thermal storage medium for both short term energy storage (diurnal) as well as seasonal or longer term energy storage. The stored low-grade energy can be extracted as required using ground source heat pumps to provide space heating and domestic hot water.

Working with the people in the community and with other stakeholders in the community, it is possible to develop an integrated district geothermal energy system to take advantage of waste energy sources in the community. Integrating waste energy sources into the system greatly reduces the size and cost of the GHX needed for such a system.

This paper presents a potential scenario demonstrating how a diesel generator in a community could be integrated into a district geothermal energy system, using the community of Lac Brochet in Northern Manitoba, Canada, as a case study.

INTRODUCTION

Many remote northern communities have limited access to energy for heating and cooling, producing hot water, lighting and operating appliances. They may not be connected to the electrical grid. If they are connected to the grid, the capacity of the connection may be limited because they are at the "end of the line". Most are not connected to a natural gas pipeline. Some of the communities are not connected to the transportation infrastructure and rely on seasonal winter road connections, water transportation or limited and expensive air connections. The limited access to energy has implications on energy cost, greenhouse gas emissions and direct pollution of the environment of the communities.

Homes and small buildings in northern Canadian communities require significantly more heating than they do cooling. In fact, most residents don't install air conditioning systems in their homes. These buildings would be considered "heating dominant" if they were heated with a ground coupled heat pump (GCHP) system. Other buildings such as ice arenas or grocery stores, however, require refrigeration and reject significant amounts of waste heat from the cooling process. These would be considered "cooling dominant" buildings if connected to a GCHP system.

In many communities there may be opportunities to take advantage of renewable energy sources that capture solar energy or biomass. Some energy sources such as solar thermal, however, do not always produce heat when it can be

Ed Lohrenz is a partner at Geo-Xergy Systems Inc., Winnipeg, Manitoba

utilized. Integrating the various available energy resources with an energy storage device increases the opportunities to meet space and water heating loads using waste or renewable energy resources that may only be available on an intermittent basis.

The ground can be used as an energy storage medium for both short and long term energy storage. Plastic pipe can be buried in a variety of configurations, including vertical boreholes or horizontal trenches or boreholes, allowing the transfer of energy between fluid circulated through the pipe and the earth surrounding the pipe. The ambient ground temperature is, in most locations, very close to the average annual air temperature of the location (G.P. Williams, L.W. Gold, 1976). When energy is added to the ground via the GHX, the temperature of the ground around the heat exchanger will increase. The energy can be withdrawn from the ground as needed, cooling the ground around the GHX.

Two things must be considered when the ground is used to store energy. First, the ground can store a large amount of energy, but it is low-grade energy. The temperature of the fluid leaving the GHX seldom climbs above 90°F (32°C) or falls below freezing. Heat pumps are needed to take advantage of the low-grade energy to use in space heating or domestic water heating applications. Secondly, a GHX warms or cools the ground around the piping to a temperature above or below the ambient ground temperature. Some energy will "leak" away, or be dissipated to the ground around it if the GHX temperature is warmer than the ambient temperature, or will be absorbed from the ground around it if it is cooler, but it does act as an energy storage medium for up to several months.

A GHX is connected to a relatively finite block of rock and/or soil. The amount of energy that can be extracted or rejected to it is limited. The GHX can be thought of as a "leaky bucket" from which one can only absorb a finite amount of energy or reject a finite amount of energy to. Energy can, however, be added to the GHX, and withdrawn later in the day, or even a few months later.

If heating dominant buildings are connected to a GHX that has energy input from other sources (cooling dominant buildings or waste heat sources), the system can continue operating indefinitely.

THE GROUND HEAT EXCHANGER (GHX)

The energy that must be transferred between the buildings and the GHX determines the amount of pipe that is required for a specific project.

The geological conditions will have an impact in the amount of pipe that is needed for a specific project. Different types of soil or rock (clay, silt, sand, limestone, granite, sandstone, etc.) have different heat transfer characteristics and specific heat capacities. More GHX piping is needed in soil or rock that doesn't transfer heat well.

The land area available for construction of a GHX has an impact on the type of GHX that can be installed for a project. This can have an impact on the cost of the GHX. A horizontal GHX can typically be installed at a lower cost than a vertical GHX, but requires more land area. A community that is prepared to work with different stakeholders in a project, such as private developers, public entities such as school boards and other levels of government, can often find space to install a GHX in a park area at a much lower overall cost than could be done otherwise.

TAKING ADVANTAGE OF HEAT SOURCES

In a cold climate, especially in small communities with few large buildings, most buildings are heating dominant, meaning, if they are connected to a GHX, they will extract more energy from the earth than they will reject to it on an annual basis. If little or no heat is rejected to the GHX, the GHX piping must contact a greater mass of the earth to collect enough energy to heat the building. A larger heat exchanger is needed to collect energy from the earth.

Most communities in Canada include an ice arena that uses a cooling tower to dissipate heat extracted from the ice plus the electrical energy used by the compressors and pumps. Studies (R. Sunye, D. Giguere, N. Galanis, R. Zmeureanu, J. Scott, O. Bellache, M. Ouzzane, ASHRAE RP-1289, 2006) show that a typical community ice arena with a refrigeration plant rejects between 1,000,000 and 2,000,000 kWh of energy during an average year, depending on the length of the season and the use of the facility. If a water cooled condenser is installed in place of an air cooled condenser, the energy can be rejected to the GHX.

Because of the distance from the electrical grid, some remote communities require diesel generators to provide electricity. Typically about 30% of the energy input is converted to electricity, and about 30% is exhaust heat. About 40% of the energy used by the generator can be diverted to a GHX instead of being wasted to the outside air through the air cooled radiator. The capacity of the generators varies depending on the size of the community, but since the generator will operate continuously, a significant amount of energy can be added to the GHX every year.

Grocery stores require refrigeration for walk in coolers and freezers and in store display cases. The refrigeration equipment can be ordered with or retrofitted with water cooled condensers. Waste energy from the refrigeration can be added to the GHX year round.

Some remote communities have been built to facilitate access to natural resources, such as trees for pulp and paper or lumber, or a variety of minerals. If resource processing takes place in the community, there may be opportunities to take advantage of waste heat from the processing.

Every community must deal with waste. Waste from homes and other activities in the community (such as logging), sewage, etc. all have to be dealt with. Commonly, refuse has simply been dumped in a landfill. New technologies to deal with waste may provide methods to access the energy embodied in the waste materials. If heat is generated from these processes, it can be added to the GHX.

Average outdoor air temperatures, even in northern Canada, average over 50°F (10°C) for three or four months every summer. If the air temperature is higher than the temperature of the GHX it is fairly simple to take advantage of the relatively warm air temperature and add energy to the ground during warm weather. This can be done by simply adding an air to liquid heat exchanger in series with the GHX piping. When the air temperature is higher than the GHX temperature the fan can be activated add energy to the GHX.

Northern Canada has long days and many hours of sunshine during the summer. Solar thermal panels can add energy to a GHX during a summer. Heat produced from the solar panels can be directed into a GHX when another use can't be made of the high-grade heat generated by the panels. The ground will store a large percentage of the energy added to it. (B. Sibbit, T. Onno, J. Thornton, A. Brunger, J. Kokko, and B. Wong, 2007) (B. Sibbit, D. MacLenahan, Reda Djebbar, J. Thornton, B. Wong, J. Carriere, J. Kokko, 2011)

LAC BROCHET, MANITOBA

To illustrate the potential benefits of developing a district geothermal energy system with energy inputs from other sources, it is useful to look at an existing community.

Lac Brochet, MB is a remote Dene community in Northern Manitoba with a population of just over 600. The community consists of approximately 150 homes, a school for 250 students, a teacherage, nursing station, church, band office and a few other buildings. The community is not on the electrical grid. The only access into the community is via a small airport or by winter ice roads for one to two months a year.

Energy in these remote communities is very expensive. Manitoba Hydro operates a diesel generator in the community, transporting oil over winter roads and storing the oil on site. The true cost of generating electricity is well over $1.00 per kWh. (G. Lane, R. Mayer, K. Kinew, 2010) Diesel generators convert approximately 30% of the energy from burning diesel to electricity. Approximately 40% is converted to thermal energy rejected to the atmosphere and 30% is wasted energy emitted to the atmosphere through the engine exhaust.

Over the year the diesel generators produce approximately 3,625,500 kWh of electricity, with a peak power supply of 654 kW. Approximately 258,100 gallons (977,200 liters) of diesel fuel was consumed to produce the power. (Canadian Off-Grid Utilities Association, 2012)

The use of the electricity in the homes and buildings is restricted to lighting and appliances. Power supply to residences is limited in size to prevent the use of electric resistance heating. The options for heating homes and buildings in these remote communities are limited. Oil can be trucked in over winter roads and stored on site, or wood can be burned.

Manitoba Hydro has and continues to review alternative technologies to produce electricity, including solar, wind, photovoltaics, biomass, bio-diesel, and small scale hydro-electric, as well as extension of power lines to these remote communities. Some heat recovery of waste heat has been done in some of the communities; mainly to reject heat to the water and sewer system to prevent it from freezing during the winter. (Manitoba Hydro, 2010) The small scale of the water and sewer system in this community, however, does not provide a significant benefit.

Energy Loads in Lac Brochet

The climate in Lynn Lake, MB is severe with an annual average temperature of 26°F (-3.3°C), and extreme minimum temperatures of -53°F (-47.1°C) Table 1 shows the monthly average temperature in the community. Lac Brochet is approximately 120 miles (200 km) north of Lynn Lake.

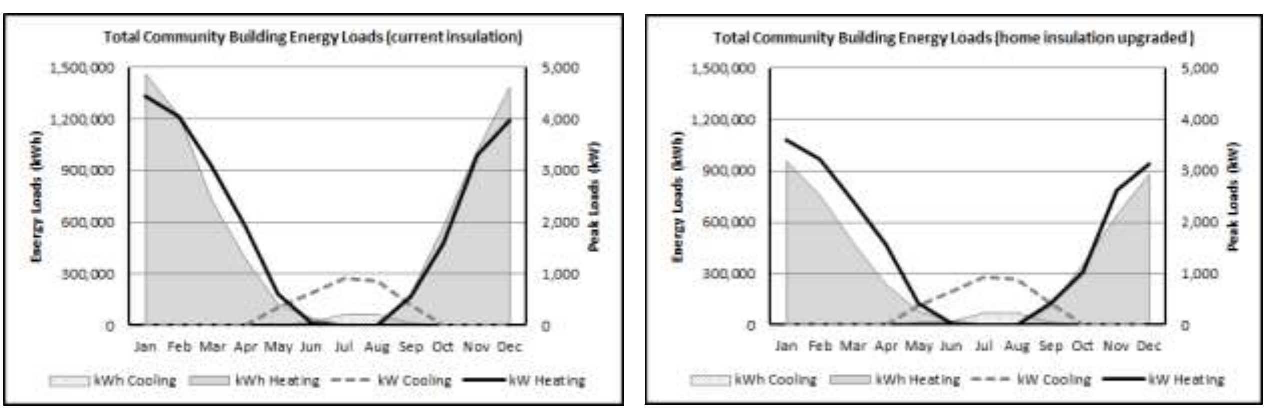
Table 1. Average monthly temperature

Avgerage Temp.	J	F	M	A	M	J	J	A	S	O	N	D	Y
°F	-13.0	-5.1	8.4	27.3	43.1	55.2	60.8	57.7	44.8	31.3	9.3	-7.8	26.1
°C	-25.0	-20.6	-13.2	-2.6	6.2	12.9	16.0	14.3	7.1	-0.4	-12.6	-22.1	-3.3

Residential Heating Energy Loads. Homes in Lac Brochet average approximately 1,000 to 1,100 square feet (90 to 100 m^2) in area. Most of the homes are constructed on a crawl space. Some of the older homes are poorly insulated wood frame construction. One or two new homes are built each year. New homes are typically insulated to higher standards. Heat losses were calculated for both typical existing homes and typical new homes. New homes are built to better construction standards and have lower heat losses. The bin-method was used to estimate the annual energy loads for the typical homes.

Non-residential Building Heating Energy Loads. There are several additional buildings in the community, including a school, teachers' residences, band office, band garage, water treatment plant, church, arena, hall, and store. The school is the largest at approximately 28,000 square feet (2,600 m^2) in area. They are heated with oil transported to the community over winter roads. In 2006, the community buildings consumed approximately 48,888 gallons (177,600 liters) of fuel oil, the equivalent of 1,902,300 kWh of electrical energy. (A. Fleming, S. Chernis, K. Zarowny, Tim Weis, 2006)

Total Community Building Heating Energy Loads. Because of the cold climate the total heating energy loads for the community are very heating dominant. There is little or no need for cooling because most of the buildings are relatively small with few internal gains. There is some refrigeration load in the store.



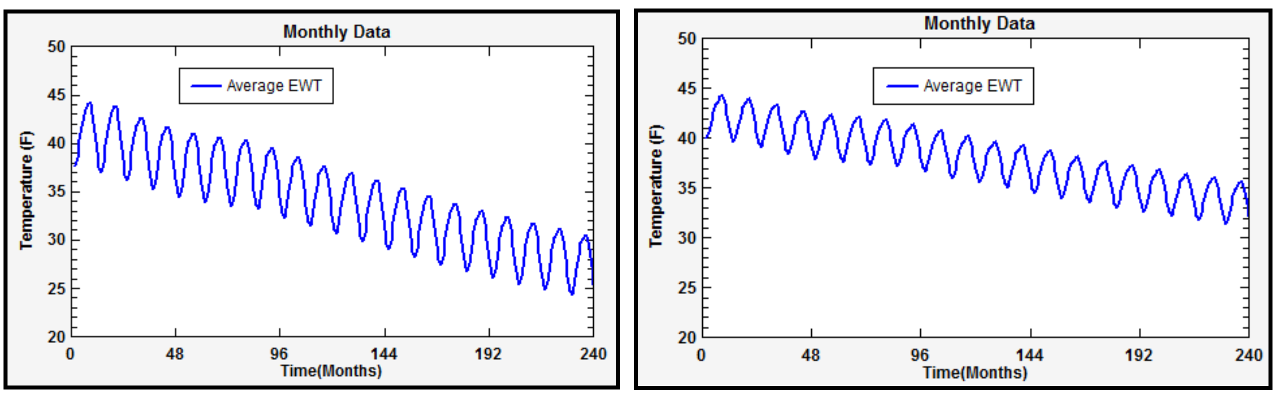
a) b)

Figure 1 *(a) This graph illustrates the total building heating and cooling energy loads with the existing homes as they are currently insulated. (b) This graph illustrates the total building heating and cooling energy loads, but with upgraded insulation standards in the homes.*

Modeling the GHX. A commercially available ground heat exchanger design software package utilizing "g" functions -- non-dimensional temperature factors that calculate a borehole field response to heat injection and heat extraction pulses -- was used to calculate the length of boreholes required. The software used is capable of modeling the long term impact on the ground and the temperatures supplied to heat pumps connected to the GHX.

The energy models developed for the community are extremely heating dominant. Very little cooling is required and little energy is rejected to the GHX. Even if the residential buildings are renovated and insulation values are increased, the buildings in the community require much more heating than cooling. Figure 2 illustrates the effect of the heating dominant project on the long term temperatures of the ground. Preliminary modeling of the GHX was based on:

- Ambient ground temperature of the area is 44°F (6.7°C)
- The GHX for these models consists of 1,000 boreholes drilled to a depth of 400' (122 m) into granite, for a total of 400,000'(121,915 m) of drilling
- Thermal conductivity of the granite is assumed to be 1.50 Btu/hr * ft * °F (2.60 W/m°K)
- Thermal diffusivity of the granite is assumed at 0.90 feet^2/day (0.084 m^2/day)



a) b)

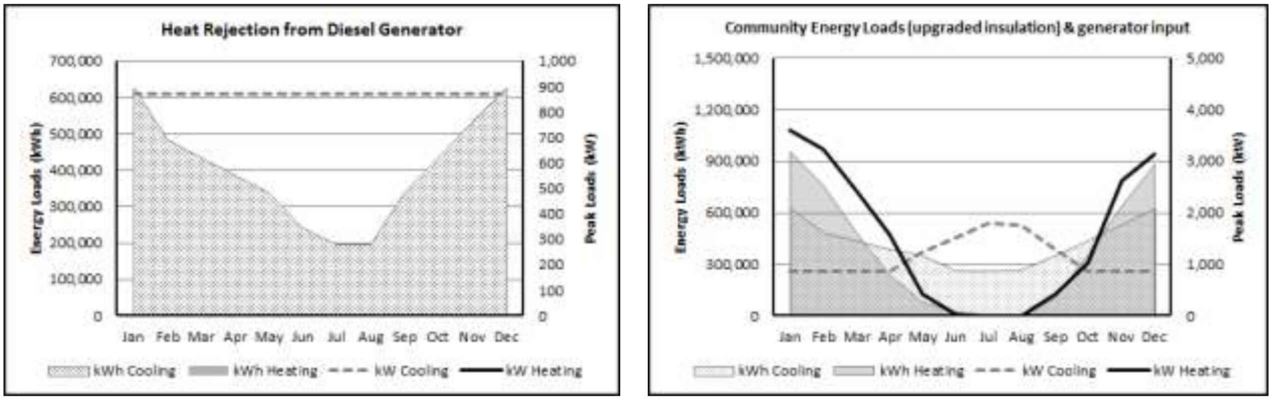
Figure 2 *(a) This graph shows predicted GHX temperatures if the existing residential and non-residential buildings are connected to the GHX. Over 20 years the average temperature of the fluid supply to the heat pumps can be expected to approach 20°F (-6.7°C) (b) This graph shows the 20 year prediction of the GHX temperature supplied to the heat pumps if the insulation values in the buildings are upgraded, reducing the heating loads. The GHX configuration used in these models is based on 1,000 boreholes drilled to 400' (122 m), for a total of 400,000' (121,915 m) of drilling.*

Waste Heat Recovery from Diesel Generator

Electricity in Lac Brochet is produced by a diesel generator. Typically, generators produce electricity at approximately 30% efficiency. The remainder of the energy is dissipated to the outside air via either an air cooled radiator or the exhaust stack. Typically about 40% of the energy is dissipated through the radiator.

With the installation of a water cooled heat exchanger on the diesel generator, energy normally dissipated to the atmosphere through the air cooled radiator can be injected to the GHX. There is a significant amount of energy that can be added to the GHX. The generator in the community has a generating capacity of 654 kW, and in 2010 produced 3,625,526 kWh of electricity. Based on the recorded capacity, the amount of energy that can be rejected to the GHX is estimated at 3,770,000 kWh at a peak of 870 kW.

For the purposes of this paper, the only heat source that was integrated into these models was the diesel generator. Other energy sources are available or could be added. These could include heat from an ice arena refrigeration plant if available, solar energy, warm air used to warm the GHX in summer months, heat from biomass, etc.



a) b)

Figure 3 (a) This graph illustrates the total amount of waste energy that can be rejected to the GHX from the diesel generator. (b) This graph illustrates the total community building heating energy load profile with the waste heat rejected from the diesel generator overlaid on it. The load profile used in this graph assumes the insulation and construction of the residential buildings have been upgraded to reduce the heating loads.

GHX Based on Building Energy Loads and Recovery of Waste Energy from Diesel Generator

A GHX can be designed based on the total energy loads of the community. Since there are almost no cooling loads in the community, other than a small amount of refrigeration in the grocery store, the amount of energy extracted from a GHX is much greater than the energy rejected to the GHX. The GHX must be designed to meet the heating loads.

The borehole field modeled in Figure 4 is not sustainable over time. The temperature of fluid supplied to the heat pumps will gradually increase to a temperature beyond the operating parameters of most heat pumps currently available.

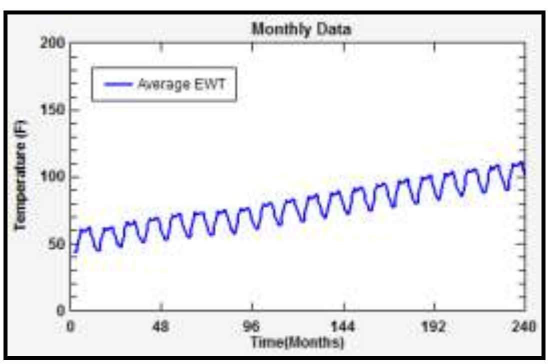


Figure 4 This graph shows the expected GHX temperatures that can be expected based on the energy load profile in figure 3(b). All of the thermal energy dissipated through the radiator of the diesel generator is rejected to the GHX. Over a 20 year period the GHX temperature can be expected to climb to over 110°F (43°C). The GHX field in this model is based on 500 boreholes to a depth of 400’ (122 m) for a total of 200,000’ (60,957 m) of drilling.

Monitoring and Controlling the Temperature of a GHX

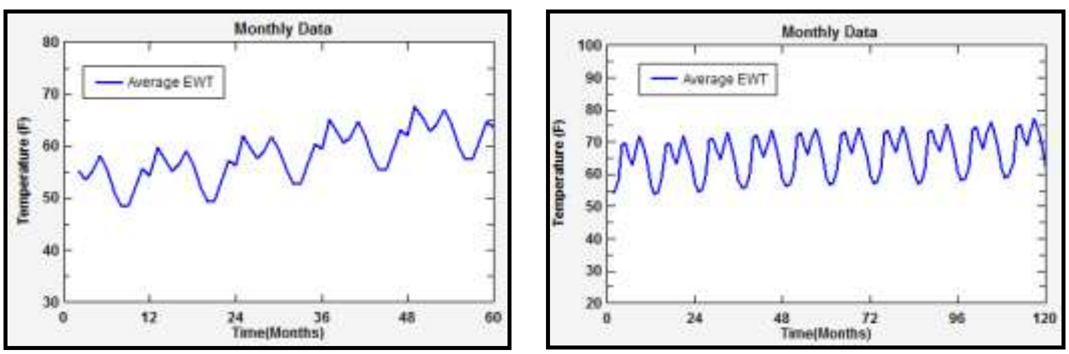
It is possible to install a water to water heat exchanger on a diesel generator to operate in parallel with an air cooled radiator, and to modulate the amount of energy rejected to the GHX. The connection of buildings to the GHX can also be completed in phases to allow the operator of a GHX to determine how much energy is removed from the GHX, both on a short term basis, and more importantly, over the long term.

One potential scenario in the construction of a district geothermal energy system in the cold climate community of Lac Brochet allows a very significant reduction in the size of the GHX field for the community. The preliminary design of the GHX field for this analysis consists of a grid of 10 x 10 boreholes to a depth of 400' (122 m), for a total of 40,000' (12,191 m) of drilling. This is a very significant reduction in the amount of drilling in comparison to the initial GHX models shown in Figures 2 and 4. (400,000' and 200,000, or 121,914 m or 60,957 m)

Phase One. The intent of the first phase of developing a district GHX field is to overcome the low ambient ground temperatures in the area, and allow the waste heat from the generator to gradually raise the ground temperature. Only the school and some of the non-residential buildings would be connected to the GHX during this phase. A large percentage of the waste energy available from the generator would be rejected to the GHX, allowing it to warm over a 2-4 year period. The temperature of the GHX would be allowed to increase to approximately 60°F (15°C). The temperature of the GHX during this phase is illustrated in Figure 5(a).

Phase Two. The intent of phase two is to allow a further increase in the average GHX temperature to approximately 70°F (21°C). The energy stored in the ground during phase one allows the connection of most of the other buildings in the community to the GHX. The energy stored in the ground allows the GHX to operate well within the operating parameters of the heat pumps connected to the system. The GHX temperatures that can be expected during phase two are illustrated in the graph in Figure 5(b)

Phase Three. During phase three, the energy rejected to the GHX by the generator, or other energy sources, is controlled to maintain a stable operating temperature in the system. This is illustrated in the GHX temperature graph in Figure 6.



a) b)

Figure 5 *(a) This graph shows the expected GHX temperature range during construction of phase one of the district geothermal system. During Phase one, only some of the community buildings would be connected to the GHX, and a large percentage of the waste energy from the generator would be rejected to the GHX. This would allow the temperature of the GHX to climb. (b) During phase 2, most of the community buildings would be connected to the GHX, while waste energy from the generator would be rejected to the GHX to allow the temperature of the GHX to increase slightly.*

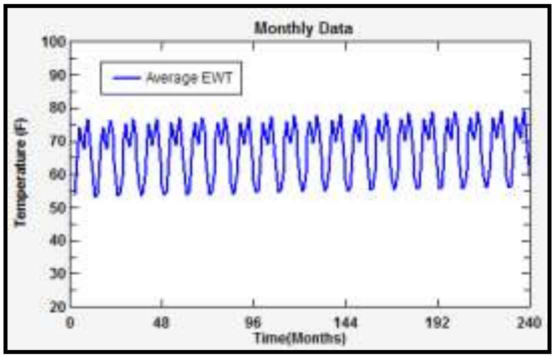


Figure 6 *After construction of the GHX is complete and most of the buildings are connected to the system, the amount of energy rejected to the GHX is controlled to maintain the optimum operating temperature.*

CONCLUSION

In a cold climate with heating dominant buildings and facilities, it is difficult, if not impossible to design a GHX that will be sustainable over time. The temperature of the GHX will continue to drop over time, and heat pumps connected to the system will operate less and less efficiently and eventually the system will fail. Adding waste energy to the GHX allows a very significant reduction in the size of the GHX field. The temperature of the GHX field can be controlled to ensure heat pumps connected to the system operate well within efficient operating conditions.

ACKNOWLEDGMENTS

The author would like to acknowledge the assistance of Ms. Inez Miller of the Manitoba Geothermal Energy Alliance for her assistance in understanding the communities in Northern Manitoba. He would also like to acknowledge Mr. Alex Fleming of Demand Side Energy for his input in understanding the energy load profiles of the community of Lac Brochet.

NOMENCLATURE

GHX = Ground heat exchanger
GSHP = Ground source heat pump

REFERENCES

G.P. Williams, L.W. Gold, 1976. Canadian Building Digest - 180
B. Sibbit, T. Onno, J. Thornton, A. Brunger, J. Kokko, and B. Wong, 2007, The Drake Landing Solar Community Project, Early Results.
B. Sibbit, D. MacLenahan, Reda Djebbar, J. Thornton, B. Wong, J. Carriere, J. Kokko, 2011, Measured and Simulated Performance of a High Solar Fraction District Heating System with Seasonal Storage.
G. Lane, R. Mayer, K. Kinew, 2010, Manitoba Public Utilities Board Act, Electricity Rates – Four Communities, Diesel Generation
Manitoba Hydro, 2010, Report on: Recommendations for Reducing or Eliminating the use of Diesel Fuel to Supply Power in Off-grid Communities
Canadian Off Grid Utilities Association, 2012, website: http://www.cogua.ca/history/manitoba_systems.htm
A. Fleming, S. Chernis, K. Zarowny, Tim Weis, 2006. Northlands Dene First Nation Community Energy Map – Energy Baseline Study
R. Sunye, D. Giguere, N. Galanis, R. Zmeureanu, J. Scott, O. Bellache, M. Ouzzane, ASHRAE RP-1289, 2006, Develop and Verify Methods for Determining Ice Sheet Cooling Loads