District GeoExchange Systems & Waste Heat Recovery

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ABSTRACT HEADING

Remote communities must often import energy to sustain life. Diesel powered generators are often employed to produce electricity in small communities that aren't connected to the power grid. Some communities have developed facilities to convert refuse to heat and/or electricity. Even if wind or solar energy can provide a portion of the electricity needs, diesel generators are often used for back-up power. In northern communities connected to the grid, there are often other sources of thermal energy such as refrigeration plants in ice arenas, grocery stores or small manufacturing facilities that create excess heat.

Waste energy is not always produced when it is needed. If the waste energy can be stored, it can be used much more effectively. A ground heat exchanger (GHX) can operate as a thermal storage medium for both short term energy storage (diurnal) as well as seasonal energy storage. The stored, low-grade energy can be extracted by heat pumps as required for space conditioning and hot water needs.

Working with the community and building owners and their design teams, it is possible to adjust peak loads and annual energy loads in buildings. This approach to building design, combined with buidings with waste heat recovery in the community can be used to balance energy loads to and from a GHX. This reduces the size and cost of the GHX and ensures the long term viability of the system.

This paper presents possible options available in remote communities to capture waste energy from buildings in the community, renewable energy and other possible energy sources. It also discusses strategies that can be used to help balance the energy loads to and from the ground.

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". 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.

In many communities there may be opportunities to take advantage of renewable energy sources that capture solar energy or biomass. These energy sources, however, do not always produce heat when it can be used. Integrating the various available energy resources with an energy storage device greatly improves the percentage of the space and water heating loads that can be met with waste energy, renewable energy or other energy resources.

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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. 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 the energy is low-grade energy. The temperature of the fluid leaving the GHX seldom climbs above 90°F (32°C) or 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 not flow through rock or soil very quickly.

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 should be thought of as a "leaky bucket" from which one can 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. The temperature range the GHX is designed to operate at is based on the design parameters of the equipment connected to it.

By connecting heating dominant buildings and cooling dominant buildings to a GHX, energy from cooling dominant buildings can be stored in the ground on a daily or seasonal basis, while heating dominant buildings can extract the energy. Other energy sources, such as solar thermal or biomass, can add energy to the GHX when it is available.

THE GROUND HEAT EXCHANGER (GHX)

The energy that must be transferred between the buildings and the GHX determines the amount of pipe that will be required for a project. An imbalance between heating and cooling loads for a project will increase the spacing required between horizontal trenches or boreholes in a vertical GHX.

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 cost than could be done otherwise. There are often opportunities to take advantage of diverse loads in different buildings or from waste heat sources in the community.

TAKING ADVANTAGE OF OTHER LOADS

In a cold climate, especially in smaller communities with few large buildings, the great majority of the buildings can be expected to require much more heating than cooling. It means that in these kinds of communities, a district geothermal energy system will most likely be heating dominant. The buildings extract more energy from the ground than they will return on an annual basis.

This means the GHX must be designed to meet the heating loads, and will be much larger than is needed to meet the cooling loads. It means that if the heating load can be reduced, the GHX will need to be made larger, but it also means that additional heat can be rejected to the GHX without increasing the size of it.

The temperature of the soil surround the GHX piping is approximately the same as the annual average air temperature of the location. In Canada this ranges from a high of about 54°F (12°C) to a low of about 42°F (6°C) (unless the ground is permanenty frozen). The soil temperature increases when heat is rejected to the GHX and drops when heat is extracted. When more heat is continually extracted from a GHX than is rejected to it, the temperature of the GHX will drop over a number of years. The efficiency of heat pumps will decrease as the temperature of the GHX drops year after year, and may eventually drop below the operating parameters of the equipment. It will eventually fail.

Many communities have heat sources in the community. They may not be thought of as a heat source, but they are heat sources. Most communities in Canada include an ice arena. Consider that, if there is a refrigeration plant to maintain the ice surface, the heat removed from the ice plus the electrical energy used by the compressor and pumps must be dissipated somewhere. Most refrigeration plants simply use a cooling tower to get rid of the heat. According to studies done by Natural Resources Canada (NRCan) 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. That leaves about 40% that can be diverted to a GHX instead of being wasted to the outside air. 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 is 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.

Larger buildings, such as schools or apartment buildings, may in some cases be cooling dominant, even in a relatively cold climate. When designing buildings for remote communities, they can, in some cases be made as cooling dominant as possible. Ensuring the building is well-insulated, efficient ventilation air heat recovery is specified, waste water heat recovery is considered, and the building is oriented to take advantage of solar loads, can all reduce the heating loads. If the community could consider making use of the school during the summer, combined with energy efficiency measures, the school building could possibly become cooling dominant and add energy to the GHX.

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

Every community must deal with waste. Waste from homes, waste from 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 ways to gain access to the energy embodied in the 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. The air temperature will be 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 a fan can be activated and energy is added to the GHX.

Northern Canada is known for long days and many hours of sunshine. Solar thermal panels can add energy to a GHX during a summer. Heat produced from the solar panels can 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.

LAC BROCHET, MANITOBA

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 only. Use of electric resistance heat is not permitted. 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.

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, 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

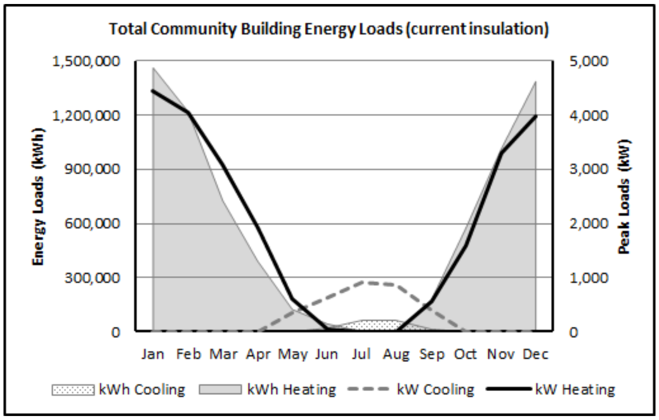
Avgerage Temp.	J	F	M	A	M	J	J	A	S	O	N	D	Y
°F	-13.0	-5.1	8.4	27.3	43.1	55.2	60.8	57.7	44.8	31.3	9.3	-7.8	26.1
°C	-25.0	-20.6	-13.2	-2.6	6.2	12.9	16.0	14.3	7.1	-0.4	-12.6	-22.1	-3.3

Residential Heating Energy Loads. Homes in Lac Brochet average approximately 1,000 to 1,100 square feet (90 to 100 m2) in area. Most of the homes are constructed on a crawl space. Some of the older homes are poorly insulated wood frame construction. Approximately 1-2 new homes are built in the community each year. New homes are typically insulated to higher standards.

Heat losses were calculated for both typical existing homes and typical new homes. The newer homes tend to be 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 of these structures at approximately 28,000 square feet (2,600 m2) in area. These buildings are all 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.



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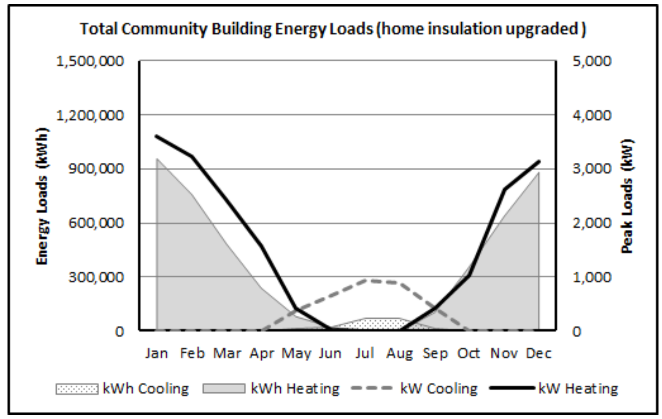

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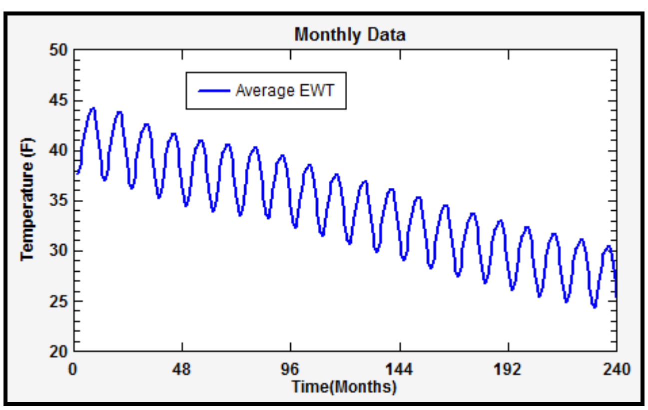
Figure 1 (a) This graph illustrates the total building heating and cooling energy loads with the existing homes as they are currently insulated. (b) This graph illustrates the total building heating and cooling energy loads, but with upgraded insulation standards in the homes.

Modeling the GHX. GHX design software was used to model the size and configuration of the GHX required to deal with the heating and cooling loads of the community. 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 very heating dominant. Very little cooling is required and little energy is rejected to the GHX over the year. 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 is drilled to a depth of 400’ (122 m) into granite
- 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)



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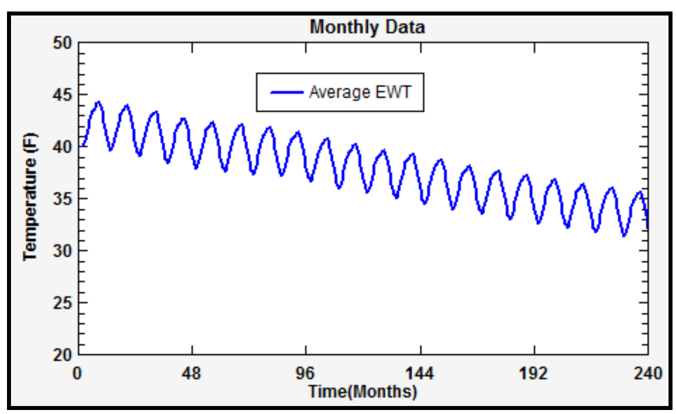


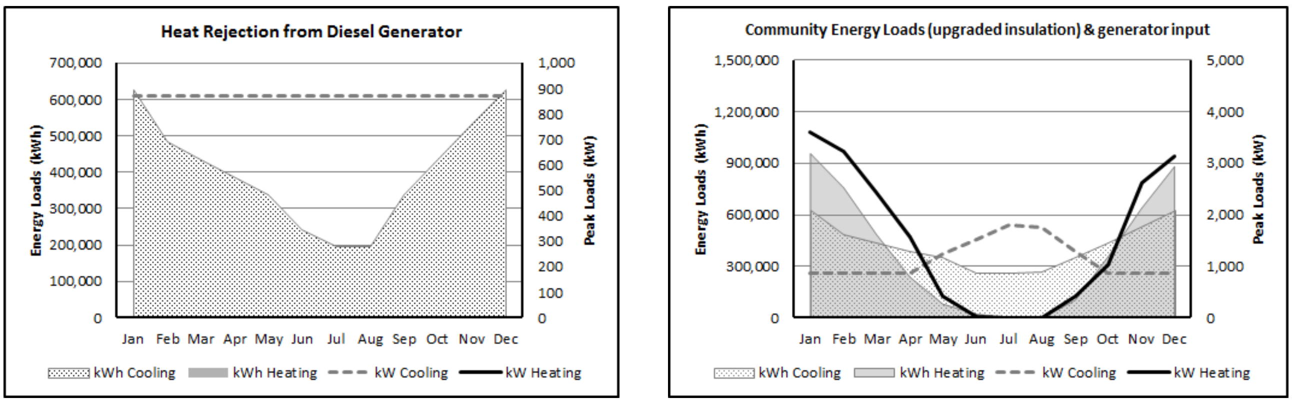
b)

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 this capacity, the amount of energy that can be rejected to the GHX is estimated at 3,767,923 kWh at a peak of 870 kW.



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.

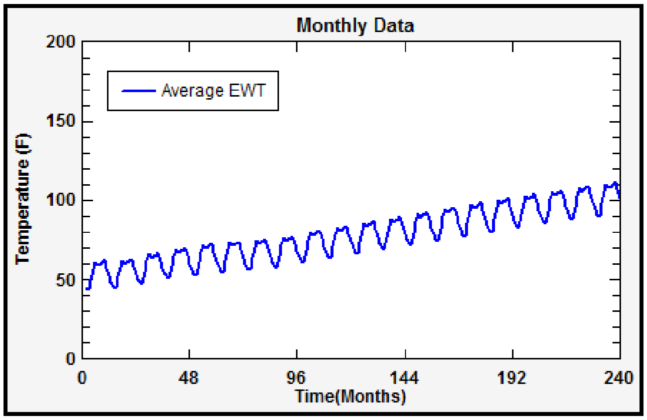


Figure 4 This graph shows the expected GHX temperatures that can be expected based on the energy load profile in figure 3(b). All of the thermal energy dissipated through the radiator of the diesel generator is rejected to the GHX. Over a 20 year period the GHX temperature can be expected to climb to 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

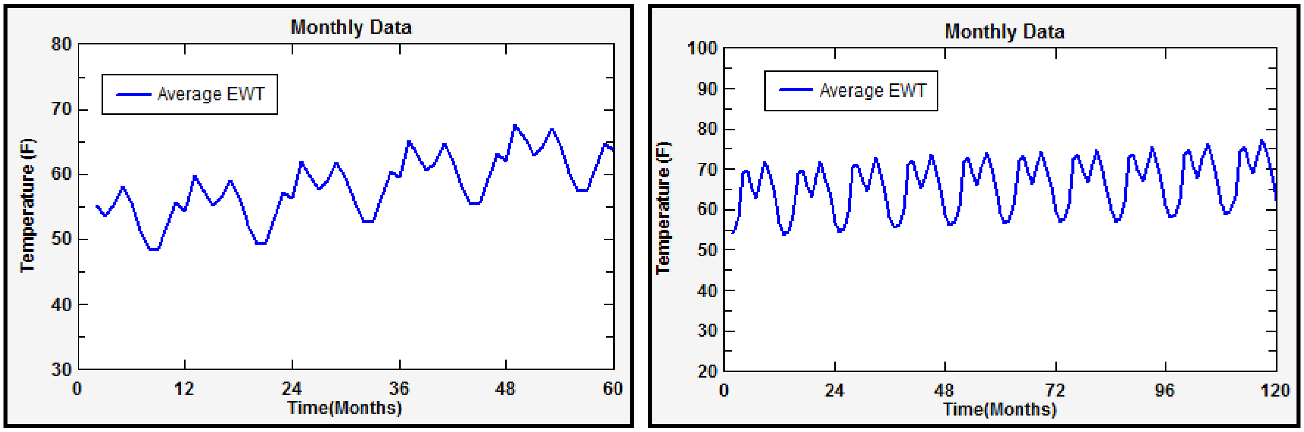
It is possible to install a water to water heat exchanger on a diesel generator to operate in parallel with an air cooled radiator, and to modulate the amount of energy rejected to the GHX. The connection of buildings to the GHX can also be completed in phases to allow the operator of a GHX to determine 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.

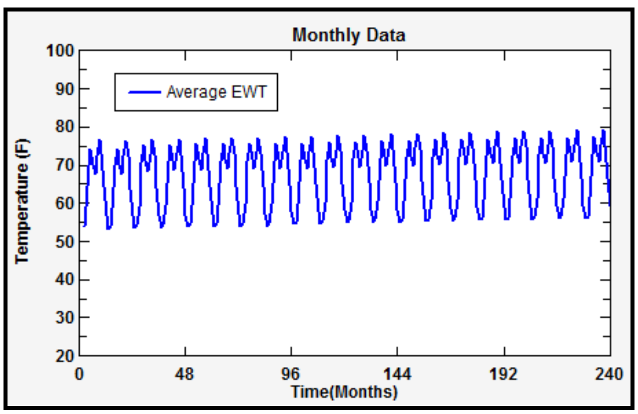


Figure 6 After construction of the GHX is complete and most of the buildings are connected to the system, the amount of energy rejected to the GHX is controlled to maintain the optimum operating temperature.

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.

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NOMENCLATURE

GHX = Ground heat exchanger

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