Faculty of Agricultural and Environmental Sciences

Department of Bioresource Engineering

BREE 495: Design 3

GEOTHERMAL HEATING FOR GREENHOUSES IN QUEBEC

François BLAIS [redacted]
Jonathan SALAMA-SIROISHKA [redacted]

December 4th, 2019

Abstract

With climate change, the idea of more sustainable agriculture is becoming very attractive to many producers. In Quebec, this trend is expected to result in a high growth of greenhouse production area and an increase in profits. These buildings, which have a very high heating demand, are typically heated by natural gas, propane or electricity. Companies like Gobeil Dion & Associés Inc. (GDA) have been working with greenhouse producers to provide economically viable and sustainable heating alternatives. This paper explores the possibility of using a geothermal heating system to heat a greenhouse in the province. The model of a typical 0.5ha tomato production greenhouse located in Cowansville was used as reference. Three systems, open loop, vertical closed loop and horizontal closed loop were compared based on many constraints: geophysical, economical, environmental, social, legal, safety and adaptability. Following this analyse, it was concluded that the best system for the model greenhouse, would be the horizontal system, but an auxiliary heating system would probably be needed during the peak demand times. This might not be the best solution for a different greenhouse due to the high variations in the ground conditions across the province.

Key terms: Geothermal, closed-loop, open-loop, greenhouse, Quebec agriculture, geoexchange, heating, propane, bi-energy

Table of contents

1.0 Introduction

One of the greatest challenges facing the 21st century is without a doubt global climate change. Over the last few decades, the atmospheric concentration of greenhouse gases (GHG) such has CO_2 - which is currently at a concentration of 406ppm - have increased exponentially due namely in part to humankind's dependence towards fossil fuels (NASA, 2013). In fact, should we continue to burn fossil fuels at a business-as-usual rate, the atmospheric concentration will rise to the order of 1500ppm (NASA, 2013).

In Canada, over 80% of GHG emissions stem from energy consumption (NRCAN, 2018a). In fact, due to the extremely cold climate, more than half of all industrial and commercial energy consumed is dedicated to space heating and water heating, as seen in figure 2 (NRCAN, 2018a). It can therefore be concluded that in order to reduce our carbon footprint, alternatives to heating must be found that do not rely on fossil fuels. While most buildings continue to heat primarily with natural gas and other fossil fuels, there has been a significant shift towards a lower carbon economy in Canada. Many businesses are doing this not only to reduce their dependence on fossil fuels and to become greener, but also due to the increasing cost of heating with fossil fuels as well as new carbon tax laws. This is true as much in large corporations located in major cities as it is in small farms in rural areas.

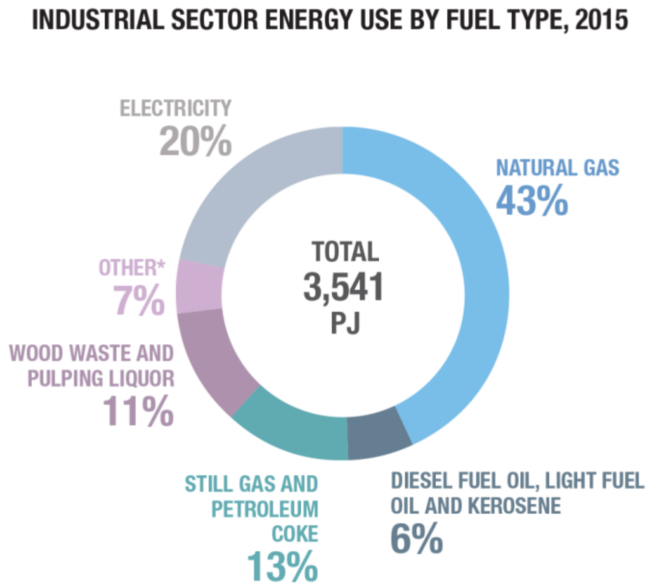


Figure 1. Industrial energy use by fuel type in Canada. Source: NRCAN, 2018a

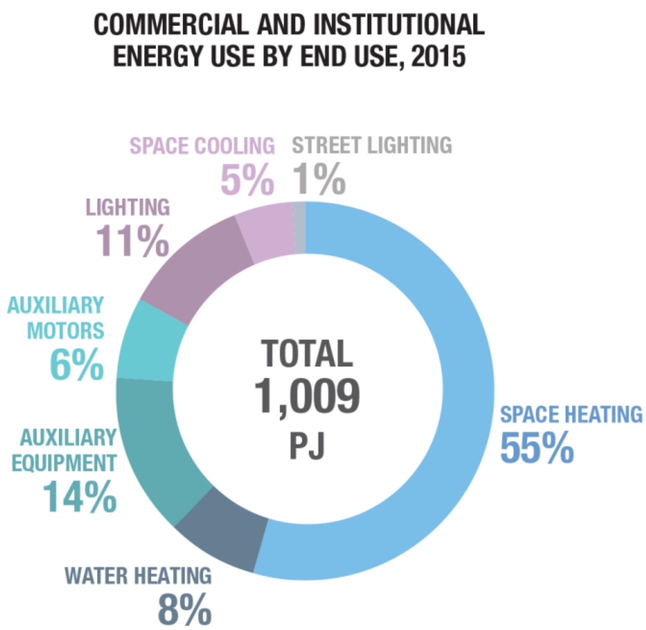


Figure 2. Commercial and institutional energy use by end use in Canada. Source: NRCAN, 2018a

In the agriculture sector, greenhouses are a well-known staple of environmentally controlled agriculture business. In an economy as competitive as agriculture, greenhouses are often used in Quebec due to the many advantages they provide such as prolonged growing seasons - often growing year round, better pest control, and higher crop yield. In Quebec, more and more fruits and vegetables are being grown in greenhouses due to their numerous benefits. From lettuce to hydroponic cannabis, greenhouse practices in Quebec are growing more and more. According to the following figure (fig. 3) by Les Producteurs de Serres au Québec (PSQ), the area of land farmed by greenhouses in Quebec is envisioned to double between 2015 and 2020. The profits from greenhouse products are also targeted to double between 2015 and 2021 (PSQ, 2017).

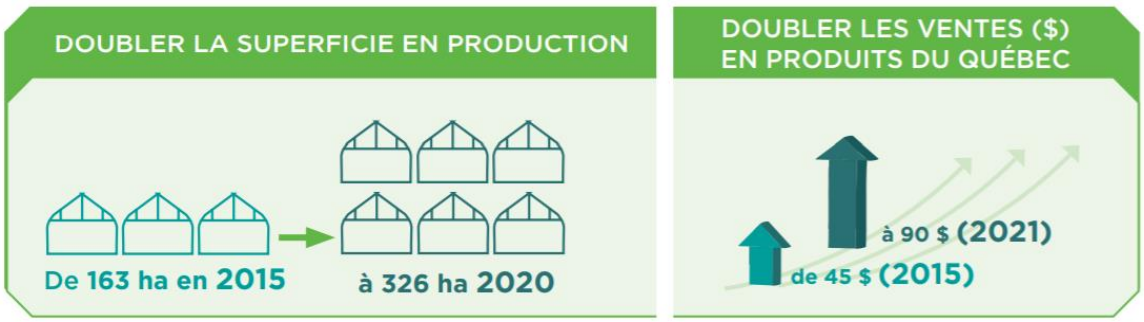


Figure 3. Growth targets of Quebec greenhouses. Source: PSQ, 2017

A challenge, however, that comes with operating greenhouses in Quebec is the weather extremes. Due to the combined cold temperatures in the winter and poor insulation capacity of glass, greenhouses require a lot more fuel and energy to be heated year round. Currently, greenhouses are primarily heated by three different methods: natural gas, propane, and electric. However, especially in the context of heating a greenhouse year round in a climate like that of Quebec, the uses of these systems become less efficient and more taxing to both the environment and producers. Therefore, the horticulture industry has had increased pressure over the past few years to reduce greenhouse gas emissions and operational costs linked to energy consumption. This is further pushed by the worldwide shift in energy policies that many governments - including those of both Canada and the Province of Quebec - have put in place to reduce the use of fossil fuel consumption. For greenhouse operators, switching to more eco friendly heating technologies also represents economic savings, as heating represents around a quarter of operational costs (Dion et al., 2010). Therefore, many businesses - including greenhouse operations - are opting to reduce their dependence on fossil fuels as well as reduce their CO_2 emissions, and changing the way that these buildings are heated is the key to solving this problem.

Companies like Gobeil Dion et al. (GDA) understand this very well. GDA are a consulting engineering firm that specializes in the implementation of biomass heating systems in agricultural buildings, greenhouse construction and energy efficiency in agricultural, industrial, and institutional buildings (GDA, 2019). For the past decade or so, GDA have been the leaders in biomass heating and greenhouse construction in the province of Quebec. With their services, businesses are able to reduce their dependence on fossil fuel based heating systems and reduce their CO_2 emissions (GDA, 2019).

The work being underlined in this undergraduate design report is a project in collaboration with GDA. The company is working with a producer who will soon be building a new greenhouse for a year long production. This client is interest in using geothermal energy to heat their greenhouse in the winter and potentially cool it in the summer. The objective of this project is to determine whether or not geothermal energy would be efficient, sustainable and economically viable for this producer and if it is, which type of geothermal system would best serve his need.

GDA is also interest in having a way to easily evaluate the pertinence of using geothermal energy for any project in Quebec, since more and more greenhouse producers are interest in it. For this reason, all the calculations were incorporated in an Excel model in which it is possible to input the characteristics of any project and get information such as the return on investment period, the energy the system must be able to provide, the GHG emission reduction, the initial cost, etc.

2.0 Costumer Needs

2.1. Initial Needs

Since the practice of heating greenhouses in Quebec is still a relatively new field of research, GDA would like two things to be provided to them during the course of this project. First is the work for converting a typical Quebec greenhouse from a conventional fossil fuel heating system (e.g. natural gas or propane) to a geothermal heating system. This includes a report on the feasibility and profitability of installing a geothermal heating system for this type of building given the heat requirements as well as a model that can then be applied to like greenhouses in Quebec that would want to convert or have a geothermal heating system installed in their business. In order to determine the feasibility of such a system, a base model that will be representative of most other greenhouses in Quebec will be created. Second is a dossier of research and any contact information that might have been accumulated during the course of the projects lifespan that will be presented to the team at GDA.

2.2. Initial Customer Needs

Based on meetings with GDA and conversations via email, demands and needs from the customer were developed for the scope of the design. The following table indicates the original notes from both communication with Érika Bouchard, a junior engineer with the company and the mentor for this project, and a meeting with Audrey Yank, senior engineer and energy analysis specialist with GDA.

Table 1. Initial customer needs based on interviews and email communications

Feasibility to convert a greenhouse to geothermal heating
Cost effective when compared to existing fossil fuel-based heating systems
To be easy to install or put in place
To reduce CO_2 emissions
Efficient compared to existing fossil fuel heating system
Minimal environmental impact
Meets groundwater laws and regulations
Long lifespan
Easy to maintain
Relatively maintenance free
Profitable
Return on investment
Cost comparative
Adaptable to fit a number of crop/growth types
Adaptable to other regions in Quebec

Following research and development of further constraints, a hierarchical list of the customer's needs was created, and other possible constraints were added. In some cases, some needs were edited or added in order to incorporate information that may be useful to the client and/or applicable to the design.

Table 2. Hierarchical customer needs with possible constraining factors for initial design

1.0 Environmental Sustainability
1.1 To reduce CO_2 emissions
1.2 Efficient compared to existing fossil fuel heating system
1.3 Minimal environmental impact
C.1 Meets groundwater laws and regulations
C.2 Efficient in cold climates
2.0 Feasibility
2.1 Long lifespan
2.2 Easy to maintain
2.3 Relatively maintenance free
F.1 Easy to operate
C.1 To be easy to install or put in place of existing system
3.0 Profitability
3.1 Instalment cost
3.2 Operation cost
3.3 Maintenance cost
3.4 Return on investment
C.1 Cost effective compared to fossil fuel-based heating systems
4.0 Adaptability
4.1 Adaptable to fit a number of crop/growth systems
4.2 Adaptable to other regions in Quebec or like climates

2.3. Weighting of customer needs

In order to determine the most important or potentially restricting needs from the client, the needs of GDA have been weighed based on what was found to be the most deciding factors. In the following table, the Analytical Hierarchy Process (AHP) was followed to create a weighted hierarchical customer needs list.

Table 3. AHP Pairwise comparison chart to determine the weighting of needs for initial design.

	Environmental Sustainability	Feasibility	Profitability	Adaptability	Total	Weight
Environmental sustainability	1.00	0.20	0.25	3.00	4.45	**10.8%**
Feasibility	5.00	1.00	3.00	6.00	15.00	**54.4%**
Profitability	4.00	0.33	1.00	6.00	11.33	**29.3%**
Adaptability	0.33	0.17	0.17	1.00	1.67	**5.5%**

2.4. Final customer needs

Following the changes in the initial design requirements and the apparition of a new client and location, it was necessary to conduct a review of the initial customer needs. Following a teleconference and email communications with GDA, the following table shows the new hierarchical customer needs for the final design.

Table 4. Hierarchical customer needs with possible constraining factors for final design

1.0 Environmental Sustainability
1.1 To reduce CO_2 emissions
1.2 Efficient compared to existing fossil fuel heating system
1.3 Minimal environmental impact
C.1 Meets groundwater laws and regulations
C.2 Efficient in cold climates
2.0 Feasibility
2.1 Long lifespan
2.2 Easy to maintain
F.1 Easy to operate
C.1 To be easy to install or put in place of existing system
3.0 Profitability
3.1 Installment costs
3.2 Yearly costs
3.3 Periodic costs
3.4 Return on investment
C.1 Cost effective compared to fossil fuel-based heating systems
4.0 Adaptability
4.1 Adaptable to other operations constraints
4.2 Adaptable to other geological regions in Quebec
4.3 Adaptable for different operation sizes
4.4 Easy to analyse thanks to a comprehensive excel model

The new hierarchical customer needs table takes into consideration the new restrictions and demands that come with a change in design, since the new client is interested in installing a geothermal heating system before constructing the greenhouse. As seen in the table, the major changes come to the adaptability factor of the project. From this, a new weighted table was created to adapt to these changes.

Table 5. HP Pairwise comparison chart to determine the weighting of needs for final design.

	Environmental Sustainability	Feasibility	Profitability	Adaptability	Total	Weight
Environmental sustainability	1.00	0.33	0.33	2.00	3.66	**13.1%**
Feasibility	3.00	1.00	0.50	5.00	9.50	**31.6%**
Profitability	3.00	2.00	1.00	7.00	13.00	**48.7%**
Adaptability	0.50	0.20	0.14	1.00	1.84	**6.5%**

In this new look at the customer's needs, it is shown that over the course between the initial design constraints and the final design constraints that the needs of the customer have also changed. This primary change in the case of this design is that profitability is considered to be paramount and not feasibility. This is due to the fact that the project must be shown to be profitable in order that GDA invest their company in expanding into the realm of geothermal heating systems on top of their current mandate of biofuel and energy efficient propane heating. Furthermore, the feasibility requirement of the project has diminished due to the confidence in geothermal energy. It has been proven time and time again, even in the heating of greenhouses of which there have been over a dozen experimental projects conducted in Quebec alone, that geothermal energy can be used to heat/cool buildings.

3.0 External Search

3.1. Geothermal Energy

Geothermal heating can be used in different ways. The most common ones are electricity generation and space heating. To produce electricity from geothermal energy, the ground must have a very high temperature. In Quebec, these temperatures are found very deep underground. Due to technological and economical limitations, the use of geothermal energy for electricity production isn't a viable option. That being said, it is still possible to efficiently use the energy stored in the ground for heating. This type of system is called a geothermal heat pump. The way to do that is to combine a low-temperature (<100°C) geothermal heat exchanger with a heat pump for space heating (Younger, 2015). Three systems compose a geothermal heat pump: The heat pump, which moves the heat between the building and the ground, the earth connection, which facilitates the heat extraction from the ground via a heat exchanger loop, and the interior heat distribution system, which conditions and distributes the heat through the building (Self et al., 2010). The focus of this paper is mostly on the first two.

3.1.1. Heat Pump System

The essential characteristic of heat pumps that makes this system possible is that they transport more thermal energy than the energy they require to run. Simply put, heat pumps use electricity to power compressors in order to control the pressure and temperature of a working fluid, usually a refrigerant, and move thermal energy between the ground and the space that needs to be heated. The operation of a heat pump follows the following five steps (figure 4) (Self et al., 2012):

1. Thermal energy extracted from the ground is transported to the evaporator.
2. In the heat pump, the refrigerant in a mostly liquid state enters the evaporator. The heat from the ground heats the refrigerant, causing its state to change to a low-pressure vapor. The temperature increases a little.
3. The low-pressure vapor enters a compressor, turning it into a high temperature and high-pressure vapor.
4. The high temperature vapor enters a condenser, in which the thermal energy of the refrigerant is transferred to the building. The refrigerant cools and condenses, resulting in a high temperature, high-pressure liquid.
5. The liquid goes through an expansion valve, reducing its temperature and pressure.

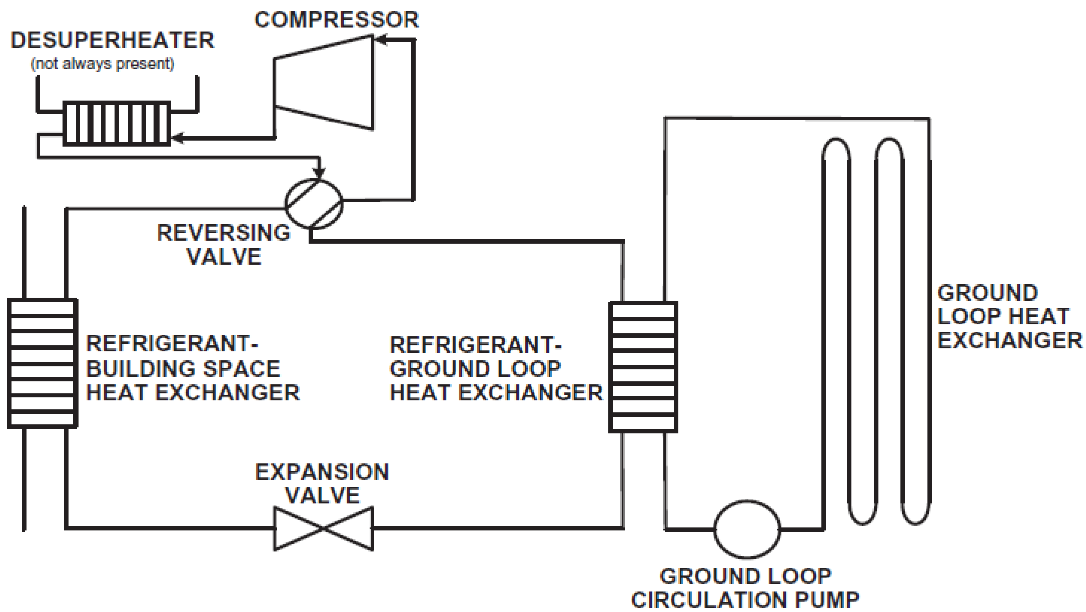


Figure 4. Basic layout of a geothermal heat pump system including a desuperheater. Source: Self et al., 2012

During the summer, the system can be reverse by adding a reversing valve to remove thermal energy from the greenhouse and store it in the ground. When this is done, the system works in the exact same way, but the heat exchangers functions are switch. The one between the heat pump and the ground becomes a condenser and the one between the heat pump and the greenhouse becomes an evaporator.

3.1.2. Earth Connection System

For a geothermal heat pump, the source of heat comes from the ground. This is possible, because, even if atmospheric temperatures change over the course of a year, at a certain depth the temperature of the ground will remain constant. A study done in Ottawa, which has a similar climate to Quebec, showed that at a depth of 5m, the temperature remains at around 9°C year-round (figure 5) (Self et al., 2012). From that point on, the deeper you go, the hotter it gets. This can also be seen when looking at the projects made by Puits Berniers in Montérégie (annex A). Coupled with a heat pump, these low temperatures geothermal system can have a significant impact on heating during the cold winter months and on cooling during the summer.

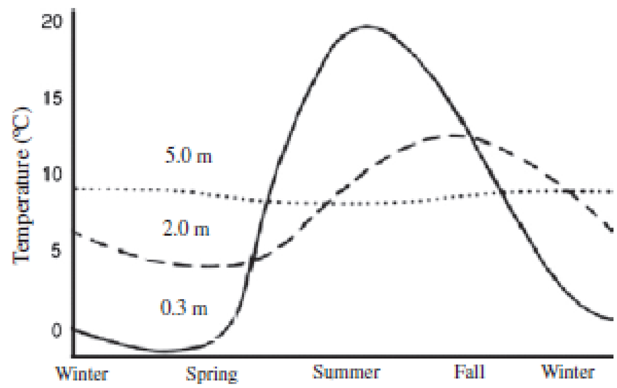


Figure 5. Temperature of the ground at 0.3m, 2m and 5m in Ottawa, Canada over a year. Source: Self et al., 2012

To bring this heat to the heat pump, different systems exist. The earth connections, or ground loop heat exchangers, are a made of an arrangement of pipes that transfer thermal energy from the ground to the heat pump using one or more fluids. This can be done using two different methods.

The first one, is single loop configuration. In this type of Geothermal heat exchanger, the liquid that flows through the heat pump is the same as the one that the one going through the ground loop. This has the advantage of eliminating the need for the ground loop circulation pump and the heat exchanger between the ground loop and the heat pump. The main disadvantage is that these systems need to be pressurize. This increases the risk of rupture, which can be very complicated and expansive to repair (Self et al., 2012). Especially for a system large enough to heat a greenhouse. Although single loop configurations are gaining in popularity, their still need to be some research and development done for them to be reliable. In projects the size of the one discussed in this report, the second type of loop is almost always preferred. For this reason, single loop configurations won't be further discussed in this report.

The other configuration is the double loop. In this configuration, one liquid is circulated in the ground loop and another one is circulated in the heat pump. The thermal energy is transferred from one to the other by a heat exchanger. This type of system is generally preferred because of the scaling and corrosion associated with geothermal fluids (Rafferty K.D., 1997). Many types of double loop configurations exist. They can be divided into two groups: open loop and closed loop. These configurations will be discussed in detail in section 2.2.

3.1.3. Heat Distribution System

The last system that compose a geothermal heat pump is the heat distribution system. Its purpose is to move the heat provided by the heat pump in the building to provide adequate heat everywhere. Two types of heat distribution systems are generally used: water to air and water to water. In North America, the first one is usually used (Self et al., 2012). In this system, air is heated by the heat pump and then dispersed in the building by the air vents. air is heated by the heat pump and then dispersed in the building by the air vents. In the water to water system, the thermal energy is distributed in the building using a liquid instead of air. This liquid is circulated in the floors or radiators. The water to water system requires lower temperatures than the water to air system and produces a more uniform temperature from the floor to the ceiling (Self et al., 2012). Still, the water to air system has other advantages. For example, an overhead air system will melt the snow during the winter, allowing for maximum sunlight to enter the greenhouse (Rafferty K.D., 1997). Both systems also have a different impact on the humidity of the greenhouse.

The design of the heat distribution system isn't part of the scope of this project but should be taken into consideration to get the most out of the ground loop heat exchanger.

3.2. Double Loop Ground Heat Exchangers

Three systems are usually used for geothermal heating with double loop ground heat exchanger. These are the systems that were considered for this project: open loop, vertical closed loop, and horizontal closed loop.

3.2.1. Open Loop Ground Heat Exchanger

The open loop system consists of pumping the water already present in the ground and using it directly for heating with the help of a heat pump. A second well must be dug to put the water back in the ground to avoid depleting the groundwater and disrupting the ecosystem by changing the temperature of surface water (figure 6). This system can be very efficient under the right circumstances, but there are a lot of regulations which can vary from one municipality to another and constraints that need to be considered. First, there must be a large enough volume of water in the ground all year round to allow the heating system to work at full capacity whenever needed. It takes between 5.7 and 11.4 liters per minutes to produce a ton of heating capacity (Self et al., 2012). Secondly, the depth at which the water is found is also very important when considering an open loop system, since it will greatly impact the installation cost of the system. Even then though, in most case, if enough water is available, it is usually cheaper than the other, since only two wells need to be dug. Finally, the water quality must also be evaluated before opting for this type of system. The heat exchanger being subject to corrosion, fouling and scaling, water containing high concentrations of iron, sulfur or limestone can greatly increase the cost of maintenance (GY et al., 2004). Low quality water will also reduce the lifespan of the ground heat exchanger, but if the groundwater is assumed to have ideal quality, the heat pump should have a lifespan of 20 years and the rest of the system should last 50 years (Hydro-Québec, 2019). This system has the advantages that it can require a smaller investment than the other two if the water isn't too deep and that the water is heated by direct contact with the ground, which result in a heat pump coefficient of performance (COP) of 3.6, which is slightly higher than that of the other systems (NRCAN, 2017).

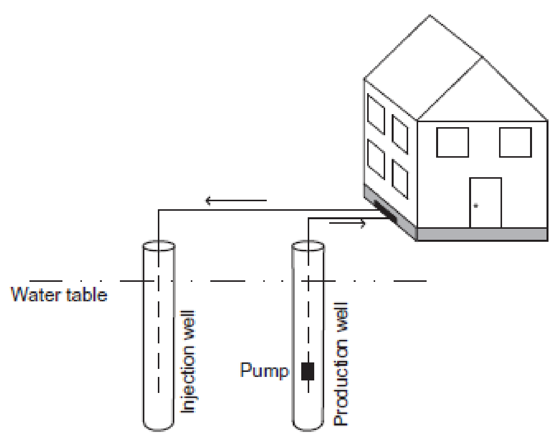


Figure 6. Open loop heat exchange system. Source: Self et al., 2012

3.2.2. Vertical Closed Loop Ground Heat Exchanger

The vertical closed loop system consists of parallel vertical tubes connected by U-shaped connectors buried deep in the ground (figure 7). The depth and number of loops depends on the quantity of thermal energy needed. For residential uses, the depth ranges from 45m to 75m. For industrial uses, it can be over 100m (Self et al., 2012). Being positioned at these depths, the temperatures are warmer and more constant, which makes it generally more efficient than shallow systems and results in a smaller piping circuit than would be needed for a horizontal closed loop system to produce the same heat (Yang et al., 2010). The federal government provides as guideline that this type of ground heat exchanger usually requires between 80m to 110m of pipes per ton of heating (NRCAN, 2017). After consulting with two different companies from Quebec (Puits Bernier and Marmott Énergies), we were told by both of them that in Quebec, a good rule of thumb is that 150pi (45.7m) of pipes is required per ton of heat. This assumption is enough for preliminary design but, for the final design, a test well to measure the exact thermal conductivity would be necessary. Unfortunately, the vertical closed loop system also has the biggest installation cost. Another advantage of the vertical ground heat pump is the relatively small land space it requires (Approx. $25m^2$/ton of heating) compared to the horizontal system (NIH, 2013). As opposed to the previous system discussed, the water isn't directly pumped from the ground. Instead, a liquid, often a mixture of water and refrigerant, is circulated in the loop (Yang et al., 2009). The liquid is never directly in contact with the ground, hence the name, and the space between the pipes and the ground is filled with a grout material to provide maximal thermal contact (Yang et al., 2009). The grout material is also required if the borehole crosses aquifers to avoid migration of surface water to the aquifer or the creation of a cross-contamination path between two aquifers (CSA C448-16). Each loop, consisting of two vertical pipes connected at the bottom by a U-bend connector, is installed in a single borehole large enough to accommodate the two pipes and filled with grout. It is important when designing this type of system to provide enough space between each vertical loop to prevent them from affecting each other and changing the ground temperature conditions (Yang et al., 2010). The heat pump for vertical closed loops have a COP around 3.3 (NRCAN, 2017). The heat pump is expected to have a lifespan of 20 years, while the piping system should last 50 years (Hydro-Québec, 2019). Due to its high investment cost and size efficiency, the vertical closed loop system is more likely to be suited for big installations rather than small independent greenhouses. A last advantage of this system is that it causes less disturbance to the surface ecosystem, drilling being less disruptive than digging trenches.

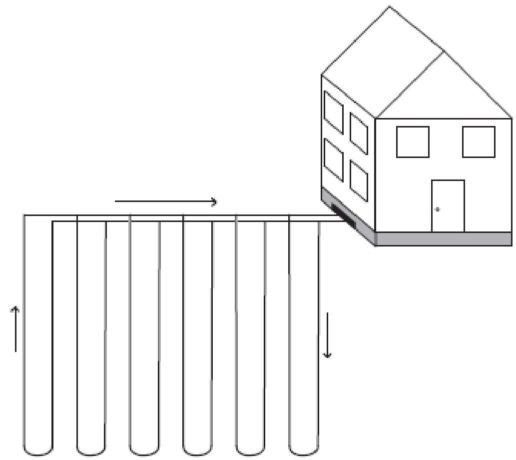


Figure 7. Vertical closed loop heat exchanger. Source: Self et al., 2012

3.2.3. Horizontal Closed Loop Ground Heat Exchanger

The last geothermal space heating system considered for this project was the horizontal closed loop system. As suggested by the name, a liquid is circulated in pipes placed horizontally in the ground. Different configurations can be used: basic loop, in series, and in parallel (figure 8). Because of the large open land area required for this system (approx. 230m²/ton of heating), it can immediately be ruled out if the space is limited (NIH, 2013). Horizontal closed loop can be a good option for greenhouses, since producers often have large land. On the other hand, the amount of heat required by greenhouses can bring these systems to require excessively large areas. These systems are usually installed at a depth between 1m and 2m. Although some successful systems have been installed at depths as shallow as 1m, it is recommended to install the pipes below the freezing line and to add some antifreeze to the heat exchanging liquid to protect the system from damage that could be caused by cold (Self et al., 2012). At these depths, the ground temperature is still subject to seasonal fluctuations caused by atmospheric temperatures and also to less predictable fluctuations caused by daily events like rain, snow, vegetation growth, shades, etc. (A.Mustafa, 2008). This makes for a less stable system than the two mentioned above. To compensate for the temperature fluctuation and the colder temperature of the ground at this depth, the horizontal system usually needs a lot more piping. To produce 1 ton of heating, 120m to 180m of pipes are needed (NRCAN, 2017). Despite that, it is often a cheaper option than the vertical closed loop due to the much lower cost of trench digging compare to drilling. According to Pierre-André Blais, project engineer at Énergir, the cost of digging trenches at these depths is around 30$/m. The same heat pumps, COP of 3.3, are used for horizontal closed loop systems and vertical closed loop systems (NRCAN, 2017). The lifespan of the heat pumps and the loop system are the same as the ones for the vertical system

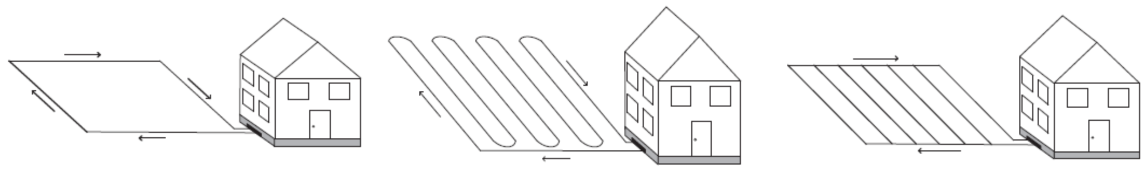


Figure 8. Horizontal closed loop heat exchanger. Basic loop (a), series loop (b), parallel loop (c). Source: Self et al., 2012

For the purpose of this project, only the three most common systems mentioned above were considered. Other low-temperature systems that seem promising but are still at an early development stage and have been known to fail on some occasion, like the spiral loop, were not considered. The same goes for systems that are efficient but are too case specific. For example, the pond loop system can be an interesting option, but it requires the proximity of a deep and calm body of water near the building, which isn't often the case for large greenhouse producers like the one studied in this project.

3.3. The state of geothermal heating in Quebec

In Quebec, the current state of geothermal heating, like in the rest of Canada, is that geothermal heating in homes and businesses is on the rise. In 2010, according to the Canadian GeoExchange Coalition (CGEC), 69.3 % of geoexchange heating systems are installed in new homes compared to 30.7 % in existing homes (CGEC, 2010). This may be explained by two factors. Firstly, Hydro-Québec has been developing aids and grants, up to $2,800 in new homes (Hydro-Québec, 2019). Second is that around ¼ of the installations on new homes in Quebec are being performed by one installer (CGEC, 2010). The following table indicates the most common geoexchange systems in the province.

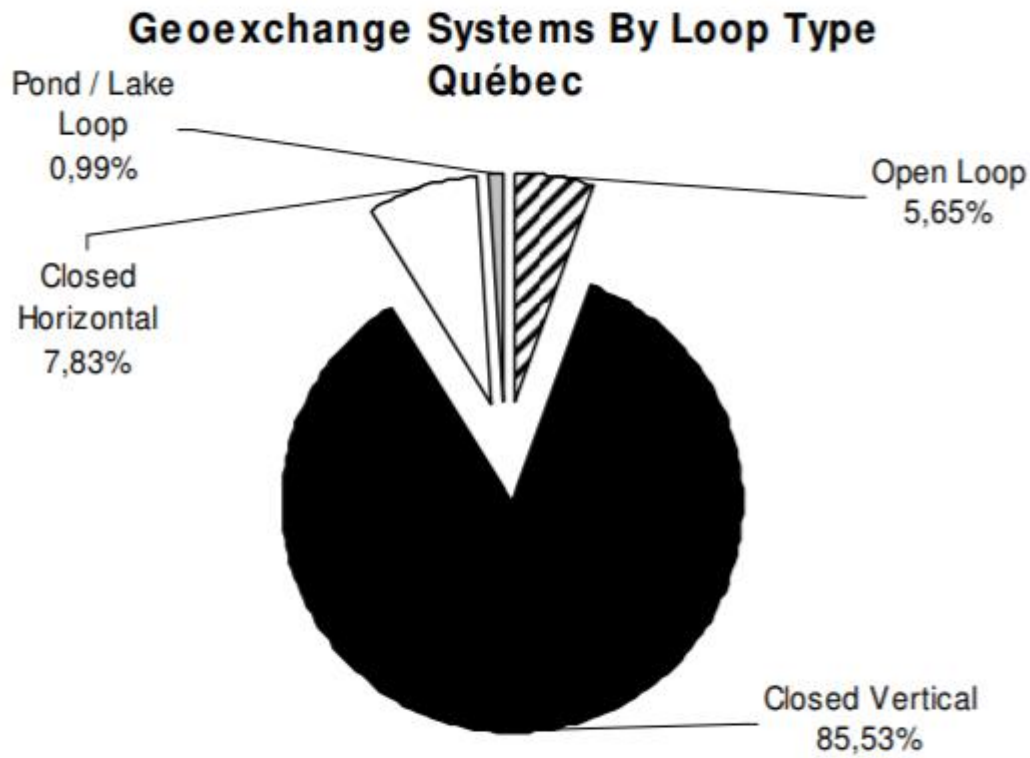


Figure 9: Geoexchange systems by loop type in Quebec. Source CGEC, 2010

As shown in figure 9, the overwhelming majority of geothermal heating units installed are vertical closed loop systems. This is primarily due to the geography and geology in Quebec, since our thermal potential is far higher far below ground. This is also a popular option as some of their other options, such as horizontal closed loops, require a large amount of land to operate.

4.0 Design Constraints

4.1. Details of the Project

The project consists of two initial phases, with the possibility of adding a third phase in the future. The first phase is the construction of the greenhouse of 6 020 m². The second phase is the construction of a service area of 366 m² connected to the greenhouse.

4.1.1. Location

The greenhouse is located in the Montérégie area[1]. The plan in annex B show the area available for the installation of a ground heat exchanger. The areas delimited by phase 3 (2.61 ha) and phase 4 (5.65 ha) could both be used for the installation of a geothermal system.

4.1.2. Climate and soil characteristics

The climatic conditions on the farm were assumed to follow the 2017 ASHRAE tables for Frelishburg, Qc, Canada (Annexe C). The coldest temperature occurs during the month of January and is -21.5°C.

As per the recommendation of Jonathan Auger from Puits Bernier, the "Systèm d'information géominière du québec" (SIGÉOM), made by "Énergie et ressources naturelle Québec" was used to do a preliminary assumption of the composition of the ground at the location. This showed that the ground in this area is composed of dolomite, dolomitic sandstone and quartzitic sandstone. Looking at four projects made by Puits Bernier near the location of the greenhouse (annex A), seems to confirm this assumption. Those projects also show which of these geological formations is dominant at each specific location, dolomite has a medium thermal conductivity while quartzitic sandstone has a high thermal conductivity. By looking at those projects, it is also evident that the geological composition of the ground is highly variable in this area and to get an accurate evaluation of the thermal conductivity of the ground, a test well would be required.

To get information on the site groundwater, the company TechnoRem was contacted. On average, the groundwater temperature is of 10°C. According to them, in this area, groundwater is usually found at depths of about 7m. However, data collected by the client from ten wells drilled on is farm, shows that through 8"pipes a flow of 100 Gallon US/min is available at a depth of 260' (79m) and 200 Gallon US/min is available at 280' (85m).

---

[1] The precise location of the greenhouse can't be divulged in this report due to a confidentiality agreement.

4.1.3. Dimension, size and materials

As was previously mentioned, the size of the greenhouse is 6 020m² of gothic type. Which is the type of greenhouses commonly use in Quebec for operations of this proportion. The greenhouse is composed of ten sections long of 65.8m and large of 9.1m. The height of the walls is 6.1m and the height at the apex is 8m. A figure with the dimension can be seen on figure 1 of Annex D. The walls of the greenhouse are made of polycarbonate 8mm, which has a heat transfer coefficient of 3.58 W/(m²*°C). The roof is made of double polyethylene, which has a heat transfer coefficient of 3.97 W/(m²*°C), but at night, thermal screens are deployed under the roof, which effectively reduces its heat transfer coefficient to 2.49 W/(m²*°C). The lower 2 feet (0.6m) of the walls are covered by 3” (76.2mm) Norex insulating panels, which have a heat transfer coefficient of 0.26 W/(m²*°C). The technical sheet of the Norex panels can be seen in annex E.

The service area as the same dimensions as the greenhouse, except for its length of 20m, and is composed of two sections. The walls are entirely made of 3” (76.2mm) Norex panels and the roof is also made of double polyethylene with thermal screens at night. The dimensions can be seen on figure 2 of annex E.

Table 6. List of materials and their heat transfer coefficients

	Material	Heat transfer coefficient [W/(m²*°C)]
Roof	Double Polyethylene	3.97
Walls	Polycarbonate 8mm	3.58
Insulation walls	Norex 3” (76.2mm) insulation panels	0.26
Thermal screens		2.49

The greenhouse and the service area are equipped with a total of 680 HPS lamps. Each of these lamps have a power of 1000W and are used all year round so that the plants have enough light throughout their photoperiod. The photo period is of 18h/day from September to April and of 11h/day from Mai to August.

4.1.4. Usage

The client wants to use the greenhouse for the production of root vegetables. For this purpose, the inside temperature must be of 22°C during the day and 18°C at night all year long.

4.1.5. Alternative to geothermal heating

In the case were geothermal heating would prove to be inadequate for this project, the alternative would most likely be propane or natural gas. Electrical heating wouldn't be efficient to heat a greenhouse year-round and the possible issues with meeting peak demand during winter months. As per the recommendation of GDA, propane was chosen as the alternative heating source to compare GHG emissions and costs. Propane also has the advantage of having a stable market value of approximately 0.45$/L.

4.2. Heat Requirement

To determine the heat required the maximum heat loss of the green house was calculated. That is, at night, when the lights are turned off and the outside temperature is -21.5°C.

The following equations were used:

$$Q_T = Q_C + Q_A, \qquad (1)$$

Where, Q_T: Total heat loss (W)
Q_C: Heat loss through conduction (W)
Q_A: Heat loss through natural air exchange (W)

The heat loss through conduction was calculated for each segment of the greenhouse (roof, walls and insulation walls) using the following equation:

$$Q_C = U \times A \times \Delta T, \qquad (2)$$

Where, U: Heat transfer coefficient (W/(m²*°C))
A: Surface area (m²)
ΔT: Temperature difference between the inside and the outside (°C)

The heat loss through air exchange was calculated using the following equation:

$$Q_A = c_p \times \rho \times V \times \Delta T \times n, \qquad (3)$$

Where, c_p: Specific heat of air (1003 J/kg*K)
ρ: Air density at -21.5°C (1.402 kg/m³)
V: Greenhouse volume (m³)
n: Number of natural air exchange per seconds

The detailed calculations are shown in annex D.

When the greenhouse and the service area are considered, the total amount of heat loss is 1287kW or 366 ton of heat. This means that the heating system must be able to provide at least 366 tons of heat for the temperature to stay at the desired level even during peak demand times.

5.0 Design Considerations

5.1. Annual Heat Consumption

To evaluate the operation cost of a heating system, the annual energy used to heat the greenhouse must be calculated. In the case of a geothermal system, this will be used to find the amount of electric power required for the heat pump. This can also be used to compare the environmental impact of different heating system.

5.1.1. Example of annual heat consumption calculation

To evaluate the annual heat consumption, the monthly heat consumption of every month was calculated and added together. The following example is for the month of January.

First, the heat loss for an average day was calculated. The average monthly temperatures were taken from the ASHRAE table in annex C, considering the difference between the day and the night.

<u>Day:</u>

Assumptions:

- The average temperature for January is -8.3°C.
- The U values can be found in table 6.
- The areas are the same as in section 3.2.
- c_p of air at -8.3°C is 1005 J/(kg*°C)
- ρ of air at -8.3°C is 1.332 kg/m³
- V and n are constant through the year, and the same as in section 3.2.

The Heat loss through conduction was calculated using equation (2):

$$Q_C = U \times A \times \Delta T$$

$$Q_C = ([U \times A]_{roof} + [U \times A]_{walls} + [U \times A]_{ins.}) \times \Delta T$$

$$= ([3.97 \times 6499.1]_{roof} + [3.58 \times 1899.5]_{walls} + [0.26 \times 188.2]_{ins.}) \times (22 - (-8.3))$$

$$Q_C = 990\,095\ W$$

The heat loss through air exchange was calculated using equation (3):

$$Q_A = c_p \times \rho \times V \times \Delta T \times n$$

$$Q_A = 1005 \times 1.332 \times 40\,358 \times \left(22 - (-8.3)\right) \times 0.00014$$

$$Q_A = 229\,177\ W$$

The total heat loss is calculated from equation (1):

$$Q_T = Q_C + Q_A$$

$$Q_T = 990\,095 + \ 229\,177 = 1\,219\,272\ W$$

To get the total heat required to keep the greenhouse at 22°C during the day, the total heat loss is multiplied by the average length of a day in January.

$$1\,219\,272W\ \times 9.3 = 11\,339\,227Wh = 11\,339kWh$$

<u>Night:</u>

The same logic is used to evaluate the heat loss during the night. With the following changes:

- $\Delta T = 18 - (-8.3) = 26.3°C$
- At night the thermal screens are pulled out, changing the roof U-value to 2.49.

Giving:

$$Q_C = 605\,739\ W$$
$$Q_A = 198\,922.4\ W$$

And

$$Q_T = 804\ 661.4\ W = 804.66kW$$

The energy required to keep the greenhouse at 18°C during the night is:

$$804.66kW \times (24h - 9.3h) = 11\ 829kWh$$

Daily:

$$11\ 828kWh + 11\ 339kWh = 23\ 167kWh$$

Summing up the to results above, we get that on average, during the month of January, the greenhouse requires 23 167kWh of energy to stay at the desired temperatures.

Once that has been established, the amount of heat gain from the lights and the amount of heat gained from the solar irradiance must be subtracted.

Heat gain from lights:

Three assumptions were made to estimate the heat gained from the HPS lights:

- The lights are open for approx. 2000h/year. (This assumption was suggested by GDA)
- The lights are used for the same duration each month.
- 30% of the power of the lights is recuperated as heat. From the "Centre d'information et de développement expérimental en serricultures (CIDES)"

$$680lights \times 1000W \times 2000h/yr = 1.36 \times 10^9 Wh = 1.36 \times 10^6 kWh/yr$$

$$(1.36 \times 10^6\ kWh/yr) \times 0.30 = 408\ 000kWh/yr$$

$$(408\ 000kWh/yr) \div 365days/yr = 1\ 117.8kWh/day$$

Heat gain from solar irradiance:

The average monthly solar irradiance comes from the ASHRAE table in annex C

The solar irradiance for the month of January is 1.55kWh/m²/day.

Multiplied by the surface area of the greenhouse, this gives a total solar irradiance of 9 281.1kWh/day.

Heat needed from the heating system:

$$23\ 167 kWh/day - 1\ 117.8 kWh/day - 9\ 281.1 kWh/day = 12\ 768.1 kWh/day$$

Finally, this amount is multiplied by the number of days in the month to get the monthly heat required on average.

These twelve results are then summed to get the annual heat the system will provide on average.

Table 7 shows the results of the previous calculations for each month.

Table 7. Average heat used by the greenhouse for heating

Month	Heating required [kWh]
January	395 762
February	194 793
March	0
April	0
May	0
June	0
July	0
August	0
September	0
October	0
November	164 393
December	407 654
Annual	1 162 603

Table 8. Average heat used by the Service area for heating

Month	Heating required [kWh]
January	54 680
February	36 734
March	15 103
April	0
May	0
June	0
July	0
August	0
September	0
October	2 568
November	26 722
December	49 115
Annual	184 922

5.2. Size of the Geothermal Heat Exchanger

The heat requirement of 1287kW calculated in section 3.2 is the peak heat requirement. This amount of heat will only be required a few times in a year. Due to the high installation cost of geothermal ground loop, designing one that will procure 100% of the heat required is almost always not cost effective, since a big portion of the system won't be used most of the time. In fact, in most climate, a system designed for 70% of the peak heat requirement will be sufficient to meet 95% of the annual heat demand of the greenhouse (Rafferty K.D., 1997). Designing a system big enough to heat the greenhouse on regular days and installing a complementary heating system to account for the peaks will help reduce the return on investment period by minimizing the installation costs and maximizing the economies. This will be discussed further in the economical analysis of section 8.0.

On average, during the coldest month of the year (January), the heating system must provide 14 531kWh daily. A geothermal heating system designed for 70% of the peak demand (900kW) could provide up to 21 605kWh daily. This means that on most days, it would be able to provide enough heat for the greenhouse and the service area. The complementary heating system would only be needed a few times a year.

The optimal size of the system will be evaluated in the economical analysis in section 8.0.

6.0 Design Selection

6.1. Evaluation of Open Loop System

The open loop system is by far the solution with the lowest installation cost, the easiest to install and the one requiring the least space. Unfortunately, the potential of such a system rests entirely on the availability and quality of the groundwater. Using the characteristics listed in section X, the amount of heat that could be extracted from the groundwater was calculated.

Assumption: For groundwater at 10°C, the minimum flow required per ton of heat is 3gpm (NGWA, 2019).

Therefore, 1gpm provides 0.333ton of heat.

Since there is 200gpm are available on the client's land, an open loop geothermal heating system could only provide 66.67tons of heat. This accounts for only 18% of the peak heat requirement of the greenhouse, which wouldn't be enough even if a bi-energy heating system is built. Another problem with this system is that 66.67tons is the maximum heat that can be extract from the groundwater. Meaning that there would be no possibility to expand the system in the eventuality that the next phases of the project were to be built.

6.2. Evaluation of Horizontal Closed Loop System

After discussing with GDA, the horizontal closed loop, which we thought was the best option at first was put aside as well. There are a few reasons for that. The first one is the uncertainties relative to the variation of soil temperature at shallow depths. There is also the very large area required for such a system which could eventually reduce the potential for expansion of the greenhouse production of the client.

6.3. Evaluation of Vertical Closed Loop System

After evaluating the three systems, vertical closed loop system was the one selected. The reasons for it were the following:

- There is a bit more expertise in Quebec for vertical closed loop than for horizontal closed loop;

- It takes approximately 10 times less space than the horizontal system;
- Loops can easily be added in the eventuality that more greenhouses would be build by the client;
- There is no variability in the soil temperature.

Another reason to use the vertical closed loop which isn't discussed in this report but could have a significant impact on the savings is the possibility to store heat in the ground, which can't be done with a horizontal system, during the summer by using it as a cooling system. This would result in a warmer ground in the winter, improving the efficiency of the heating system.

6.4. Pugh Chart

Table 9 below presents the selection process in a Pugh chart. The open loop system isn't represented in it since there isn't enough groundwater to use it.

Table 9. Selection Pugh Chart

		Geothermal heating systems			
	Weight factor	Vertical closed loop		Horizontal closed loop	
Criteria		Rating	Weight	Rating	Weight
Installation Cost	3	-1	-3	1	3
Environmental Impact	2	1	2	-1	-2
Area required	1	2	2	-2	-2
Feasibility	2	1	2	-1	-2
Lifespan	2	0	0	0	0
Operation Cost	3	0	0	0	0
Efficiency	2	1	2	-1	-2
Maintenance	3	0	0	0	0
Expansion potential	2	1	2	-1	-2
Heat storage	2	2	4	-2	-4
Score			11		-11

Ratings: -2: worst, -1: slightly worst, 0: equivalent, 1: slightly better, 2: best

7.0 Greenhouse Gas Emissions Reduction

The following calculations are based on the average annual heating of the greenhouse.

7.1. Geothermal

The only emissions produced by the geothermal system once it is installed come from the electricity used to power the heat pump. This power is easily measured with the following equation.

$$COP_{HP} = \frac{Q}{W}$$

Where Q is the useful heat supplied by the heat pump and W is the work required by the pump. As mentioned in section 2.2.2, the COP of the heat pump for a vertical closed loop system is assumed to be 3.3.

The GHG emissions produced by the use of electricity can be found on Hydro-Québec's website. It is evaluated at 20.72g CO_2eq/kWh.

Using the average annual heating needed,

$$W = \frac{1\ 347\ 525 kWh/yr}{3.3} = 408\ 341 kWh/yr$$

Then, the annual GHG emission is,

$$20.72 g\ CO_2 eq/kWh \times 408\ 341 kWh = 8\ 460\ 826 g\ CO_2 eq = 8.46\ ton\ CO_2 eq$$

7.2. Propane

According to the United-States environmental protection agency (EPA), propane heating emits the following greenhouse gases:

Table 10. GHG emissions associated with propane heating

	Per gallon	Per L
g CO_2	5720	1511.06
g CH4	0.27	0.0139218
g N_2O	0.05	0.0132086

To compare with the emissions of the geothermal system, these emissions are converted to CO_2 equivalent using the IPCC values for global warming potential seen in table 4.

Table 11. CO_2 equivalent of CH_4 and N_2O

Gas	Global warming potential (GWP)
CH_4	25
N_2O	298

To get the CO_2eq, the emissions are multiplied by the GWP.

Again, according to the EPA (see annex F), propane produces 0.091 mmBTU/gallon (7kWh/L).

$$Volume\ of\ propane = \frac{1\ 347\ 525\ kWh}{7kWh/L} = 192\ 504L$$

$$Masse\ CO_2eq = 192\ 504 \times [(1511.06) + (0.0139218 \times 25) + (0.0132086 \times 298)]$$

$$= 291\ 709\ 821.4\ g\ CO_2eq = 291.71\ ton\ CO_2eq$$

Using these values, we are able to determine the percent reduction in CO_2 emissions to be 97.1%.

8.0 Cost analyses

With the cost of fossil fuels constantly increasing, the costs associated with the tax on carbon, and governmental incentives and subsidies, and the comparatively cheap operating cost of the system, the use of a geothermal heating system is becoming more and more economically viable option for heating in both residential and commercial buildings.

When comparing geothermal heating and cooling systems for residential use with other conventional heating and cooling systems, it has been largely proven that geothermal energy is an economically sound and viable alternative. In Quebec, most of the heating systems that are installed are vertical closed loops, accounting for approximately 86% of the market in residential and commercial uses, with payback periods being as low as 2 years in some cases (CGEC, 2010). As with residential and commercial heating using geothermal energy, the capacity and thus the cost and the payback period of geothermal heating pumps and units vary greatly from one project to another. In the case of a new building, the factors that may affect the payback period are not as numerous as those that are associated with older buildings, which may already have a pre-existing heating/cooling system, antiquated thermal envelope, and other restrictions that could apply to older buildings.

For the purposes of heating a greenhouse that will be built, the factors affecting the payback period of the system are as follows:

- The system type, price, and associated costs (includes installation, earth moving, drilling, landscaping, limited access, grouting, etc.)
- The operation size
- The operation heat demand (taking into account heat from lighting systems, plant requirements, night/day requirements, etc.)
- The operation's thermal envelope
- The soil quality (may affect installation)
- The soil's thermal quality and exchange capacity

As for the purposes of heating a greenhouse, it is important to recall that the demand for heat is higher and must be held constant in order to ensure optimal growing conditions for crops. This is also affected by the large size of greenhouse operations as well as the lack of thermal insulation that a commercial or residential building may have. Therefore, unlike most commercial uses, in order to determine whether geothermal energy should be used to heat/cool a greenhouse, a holistic cost analyses must be done in order to determine the payback period and savings during the system's life-cycle.

As with many geothermal heating systems, these systems are often designed to meet a certain portion of the heat required to the building. For the purposes of this design, as recommended by Marmott Energy, a geothermal heating company, the portion of geothermal heat to the total heat required for the entire greenhouse operation and its extension will be for a portion of all heat. For the remainder, this would be delivered by either a conventional propane heating system or, in the case of GDA, a biomass heating system. For the purposes of this design and the requirements by the client, only conventional propane will be considered.

8.1. Installation costs

When it comes to analysing the installation cost of a geothermal heating/cooling system, the costs can vary greatly from region to region depending on the thermal properties of the soil, the availability of groundwater, the soil structure, and the amount of land available. In the case of a vertical closed loop system, as is the case with almost all geothermal heating, the initial cost is what is highest. This is due primarily to the high cost of installation that these systems necessitate. In the case of a vertical closed loop system, the installation costs can primarily be associated to the costs of borehole drilling, grouting, installation, and associated materials and machinery. This entire process is done by companies that are specialized in geothermal heating system installation, such as Puits Bernier, a local geothermal heating company that provides a variety of wells for heating in the area. Based on conversations with Jonathan Auger, a project manager with Puits Bernier, and Colas Bohy-Provost, a project manager for Marmott Energie, we were able to determine the following based on our current heat demand and the thermal properties of the soil in the area.

The current heating demand in the greenhouse, based on the model calculations and the assumptions made for heat delivery, is approximately 1029.6kW. Following the conversion of the heat requirement to tons and converting heat requirement to depth, the number of wells was determined for both options given by professionals in the area. In option A, the number of wells is larger but they are not as deep while the second option has fewer wells at a deeper depth. The determining factor for this design in the end would be between: (1) How much room would each of these installations require; and (2) what is the comparative cost associated to the drilling depth of each system?

Table 12. Comparison of installation costs

	Installment cost					
Percent geothermal (%)	50		70		90	
Heat requirement (in kW)	643.5		900.9		1158.3	
Heat requirement (in tons)	182.9760075		256.1664105		329.3568135	
Well depth (in ft)	500	800	500	800	500	800
Well depth per heat units (ft/ton)	150					
Total number of wells	55	34	77	48	99	62
Cost per well (CAN$/well)	13300	18400	13300	18400	13300	18400
Installation cost (CAN$)	**$730,074.27**	**$631,267.23**	**$1,022,103.98**	**$883,774.12**	**$1,314,133.69**	**$1,136,281.01**
Area for installation (m^2)[a]	246.4492012	141.5603694	361.9026334	211.0217557	479.5601854	282.2256519

[a]: Assuming a spacing of 6m based on recommendations from Mr. Auger.

Following the analysis summarized in table 12, it was determined that it was best to go along with option B presented by Marmott Energie. Although the depth is deeper, the total area to install the system is lower than that of option A. Furthermore, the total cost of installation is estimated to be lower than that of A by about 15.67%.

Despite these estimations and assumptions, for a project of this scale, it is highly recommended by both companies that a series of exploratory wells are dug beforehand in order to study the exact thermal conductivity of the soil and to map out an area that would serve as the geothermal heating source. This is done in order to get a clearer understanding of the soil's heat profile and will help in providing a more holistic assessment of the best system depth to choose from.

8.2.Annual Cost

According to Hydro Québec, a geothermal system can save up to 60% on heating costs associated for residential uses (Hydro-Québec, 2019). While greenhouses are quite different, the annual cost to the heating systems is largely the same as those used in residential uses. The annual costs associated with a vertical heat exchanger include the cost of operating the system and the costs associated to maintenance. The cost of operation of the system is largely summed as the costs associated with energy in the system. In the case of a vertical closed loop system, the operating costs associated with energy production is approximately 3.28¢/kWh[1].

8.3. Periodic cost

The periodic costs of a vertical closed loop system primarily considered the cost of maintenance and replacement in the system. In the case of a geothermal system, the costs associated with replacement in the system are relatively low when compared to other conventional forms of heating. According to a cost analysis done by the Oregon Institute of Technology, the costs associated with replacement in a vertical heat exchanger are most commonly attributed to the compressors that would usually need to be replaced after 20 years of operation at an estimated cost of about $30,000 (Lund et al., 2006). Compared to the rooftop and outdoor heating units, with an expected lifetime of 15 to 20 years and a replacement cost of about $40,000 (Lund et al., 2006).

Maintenances will therefore be limited to the underground system but expected to be conducted regularly on the heat pump. Furthermore, the lifetime of such a system is said to be approximately 50 years for the piping and 20 years for the heat pump, making the system more reliable than a propane heating system, which last between 10-20 years according to GDA.

8.4. Funding and Financial Incentives

In projects that pertain to sustainable development, energy and heating efficiency, and renewable resources, there are a number of funding and incentive programs available to businesses. These range from private funds to governmental incentives (federal, provincial, and municipal) (NRCAN, 2018b). A list of possible incentives and funds can be found throughout the Government of Canada's Business website (NRCAN, 2018b). In Quebec, Hydro-Quebec offers up to $2,800 for homeowners who wish to install a geothermal heating/cooling unit to their home. Additional financial assistance is also available for geothermal heating/cooling systems through Novoclimat et Renoclimat programs offered by the Quebec government energy efficiency agency (NRCAN, 2018b).

[1] Value provided by GDA.

In order to qualify for governmental and private funding, a geothermal heating system must first be approved by the Canadian Geoexchange Coalition (CGC) (NRCAN, 2018b).

8.5. Emission Economy

Due to a worldwide push to reduce greenhouse gas emissions, many businesses, including those in Canada, are imposed to a carbon tax. A carbon tax is a fee that is imposed by tonne of emissions from fossil fuels. They are meant to incentivize businesses to lower their use of fossil fuels and their emission of greenhouses gases. In Quebec, converting heating systems to more emission efficient systems not only lowers the carbon taxes for the business, but also introduces the possibility of a cap-and-trade economy, where the businesses that do not emit as much can sell their emission allowances - put in place by the provincial government - to other businesses. Currently, according to the Globe and Mail, most companies in Quebec are requiring to purchase extra caps on their emissions. In fact, most of these are being bought from business not in Quebec but in California, where businesses have been reducing their emissions and therefore their emission caps are sold at a reduced price (Globe and Mail, 2019). Should geothermal heating technology work, this could not only mean a reduced operating cost for businesses, but also an incentive to further promote the growth of the Quebec economy and as the Province's reputation as a leader in green business.

8.6. Certifications

Many certifications are available to businesses that have developed measures to adhere to sustainable development, energy and heating efficiency, and renewable resources. These include LEED® and certifications from the Canadian GeoExchange Coalition (CGEC), which can help establish a business as a leader in green business. Having certifications also helps in the recognition, increased lease up rates, healthier and cleaner work conditions, and lower use of energy, water and other resources. In Canada, buildings and industries can apply for and receive an ENERGY STAR® rating, which is a partnership with the Canadian government to incentivise homeowners and businesses to make energy efficient buildings, technologies, and products more available and visible to Canadians (NRCAN, 2018b).

8.7. Net present value of alternatives

For the purposes of the scope of work of this design, and as per the recommendations of our client, the following assumptions were made in order to compare the net value of the system:

The escalation rate of the annual maintenance costs, the annual energy costs, and the cost of propane fuel remain constant.

- The cost of propane is 0.45$/L[1] .
- Lifetime of a geothermal heating unit is 50 years[1].
- The cost of geothermal heating is 0.03$/kWh.
- Lifetime of a propane heating unit is 20 years[1].
- Project life is 50 years.

The alternative heating method that the geothermal system is being compared to, as per the instructions of our client company, is propane. Propane is a common fuel used in the heating of greenhouses in Quebec and, according to GDA, is a fuel that has remained at a constant cost recently but is projected to become more and more expensive in the coming years. Following our client's instructions, the cost of propane is assumed to be 0.45$/L. The conversion of L propane to kW of heat is between approximately 6.465 to 7.069 kW. It is also assumed that there will need to be periodic costs done to both the geothermal system and the propane system as heat exchanger replacement or repairs based on the aforementioned life-cycle of both of these systems.

[1] Assumptions made based on recommendations provided by GDA.

Table 13. Costs comparison of different bi-energy heating systems

Heating system (by percent heated)	Capital cost (in $CAN)	Annual costs (in $CAN)		Periodic costs (in $CAN (after year 20))[c]	Net present value of 50-year life-cycle cost (in $CAN)[d]
		Energy	Maintenance[b]		
Option A (50% geothermal; 50% propane)	$731,623.22	$76,139.57	$2,284.19	$52,500.00	$4,757,811.05
Option B (70% geothermal; 30% propane)	$943,987.71	$61,854.98	$1,855.65	$47,500.00	$4,224,519.06
Option C (90% geothermal; 10% propane)	$1,156,352.20	$47,570.39	$1,427.11	$42,500.00	$3,691,227.08
Option D (0% geothermal; 100% propane)[a]	$200,711.98	$111,851.05	$3,355.53	$65,000.00	$6,091,041.00

[a]: Assuming $CAN 31,43 per m^2 of greenhouse (CRAAQ, 2017).

[b]: Assuming 3% of yearly energy costs based on recommendations from GDA.

[c]: Assuming $CAN 40,000 for geothermal and $CAN 65,000 for propane.

[d]: Assuming a project lifespan of 50 years.

As seen in Table 13, the installation cost of the systems relying on geothermal increases based on % geothermal exploited. However, the cost of geothermal heating, 0.03$/kWh, is far smaller than that of propane at 0.07$/kWh. This along with a lower cost of maintenance and periodic costs, far lower due to the higher lifespan of geothermal components, drives the cost of the geothermal systems far below that of a conventional propane based system in the long run.

Based on the following information, the payback period and total cost of each system is as follows:

Table 14. Payback period comparison of different bi-energy heating systems

Year	Cost (in $CAN)			
	Option A	Option B	Option C	Option D
0	$731,623.22	$943,987.71	$1,156,352.20	$200,711.98
1	$810,046.97	$1,007,698.34	$1,205,349.70	$315,918.56
2	$888,470.73	$1,071,408.96	$1,254,347.20	$431,125.14
3	$966,894.49	$1,135,119.59	$1,303,344.70	$546,331.72
4	$1,045,318.24	$1,198,830.22	$1,352,342.19	$661,538.30
5	$1,123,742.00	$1,262,540.85	$1,401,339.69	$776,744.88
6	$1,202,165.76	$1,326,251.47	$1,450,337.19	$891,951.46
7	$1,280,589.51	$1,389,962.10	$1,499,334.69	$1,007,158.04
8	$1,359,013.27	$1,453,672.73	$1,548,332.18	$1,122,364.62
9	$1,437,437.03	$1,517,383.35	$1,597,329.68	$1,237,571.20
10	$1,515,860.78	$1,581,093.98	$1,646,327.18	$1,352,777.78
11	$1,594,284.54	$1,644,804.61	$1,695,324.68	$1,467,984.37
12	$1,672,708.29	$1,708,515.23	$1,744,322.17	$1,583,190.95
13	$1,751,132.05	$1,772,225.86	$1,793,319.67	$1,698,397.53
14	$1,829,555.81	$1,835,936.49	$1,842,317.17	$1,813,604.11
15	$1,907,979.56	$1,899,647.12	$1,891,314.67	$1,928,810.69
16	$1,986,403.32	$1,963,357.74	$1,940,312.16	$2,044,017.27
17	$2,064,827.08	$2,027,068.37	$1,989,309.66	$2,159,223.85
18	$2,143,250.83	$2,090,779.00	$2,038,307.16	$2,274,430.43
19	$2,221,674.59	$2,154,489.62	$2,087,304.66	$2,389,637.01
20	$2,352,598.35	$2,265,700.25	$2,178,802.15	$2,569,843.59

As shown in table 14, the payback period for a geothermal system to surpass a conventional propane one is approximately after 15 years of operation. While this value is within the acceptable range given to us by GDA of 10-15years, this does not take into account the added benefits of incentives and governmental and private funding for projects that promote more environmentally sustainable heating. Should these be applied, the payback period can be reduced significantly. Furthermore, over a longer period of time the geothermal option becomes far cheaper than the propane based system due to their cheap heating costs, cheap maintenance, and inexpensive periodic costs.

To resume, heating a greenhouse in Quebec accounts for a significant portion of a production's annual expenses (Proulx-Gobeil et al., 2015). Following this holistic economic analyses of geothermal heating systems, geothermal heating can drastically reduce the cost of heating a greenhouse. While the initial cost of installation is expensive, the relatively inexpensive annual costs and periodic costs outcompete conventional fossil fuel based systems and incentives further reduce the cost of these systems.

9.0 Project lifecycle

9.1. Preparation

9.1.1. Building and site assessment

In the case of a project of this scale, some preparatory work is to be done in order to mitigate the risks of any environmental damage as well as understanding the particular heating potential of the soil in order to map out a heating area. This is an important process as many of the risks to both injury, cost, and the environment can be mitigated by being properly prepared beforehand.

Land availability and soil structure and type will provide an indication of what form of geothermal heating system should be installed and to what extent this geothermal potential can heat/cool the targeted structure (DNRE, 2010).

As per the recommendation of numerous geothermal heating providers in the area, it is recommended to have professionals come in and do some exploratory well digging in order to determine the exact geology of the specific site as well as the heating potential of the soil at various depths. This will not only give us specific information on geological mapping in the area, but it can also give us an indication of the presence of nearby aquifers and other sources of groundwater (DNRE, 2010).

9.1.2. Energy model

At this point in the design, once the proposed system, location, and other data are obtained from the field, the project consultant may then choose to run the proposed system through a holistic heat model (DNRE, 2010). This will help in determining if the system will run adequately and demonstrate that the heating system is well positioned and balanced.

9.2. Installation

9.2.1. Borehole Drilling

In the case of a vertical closed loop system, this will necessitate the construction of many boreholes. During the drilling of a borehole, a drilling fluid usually consisting of a bentonite clay viscosifier and a mixture of water is circulated to form a filter cake along the walls of the hole to prevent collapse (DNRE, 2010). This fluid remains until the piping is installed before grouting. Once installed and before grouting, the fluid is thinned out until it's density is lower than that of the grouting material (DNRE, 2010). In accordance with environmental safety measures, the water used in drilling the boreholes should not be surface water unless supplied by a municipal water supply system. Furthermore, the water that would be used for drilling purposes should be potable water that contains a free chlorine residual of >10mg/L (DNRE, 2010). This should be checked prior to use.

9.3. Materials

9.3.1. Grouting

When installing a vertical closed loop system's piping, grouting or sealant must be added between the piping and the borehole. Grouting is to be added in a manner that will prevent surface or near surface water contaminants into nearby aquifers and will prevent the water from different aquifers from mixing (DNRE, 2010). In order to prevent this, grout must be added in the borehole uniformly from top to bottom using a tremie pipe of no less than 1.25 inches (DNRE, 2010). This should be done until the grout density is constant throughout the entire borehole and should be monitored by a professional.

Based on geological conditions, there are a range of grouting materials that can be used in vertical closed loop installation. The following table can be used to find an appropriate grouting material based on soil properties.

Table 15. Recommended grouts based on geological conditions (DNRE, 2010)

Geological conditions	Recommended grouts
Saturated unconsolidated sand, gravel, clay, or a combination thereof	Neat cement, cementitious, concrete, bentonite, thermally-conductive
Unsaturated, unconsolidated sand, gravel, clay, or a combination thereof	Neat cement, concrete, cementitious, thermally-conductive bentonite
Consolidated geologic formations, such as sandstone, shale, limestone, dolomite, granite, schist, or conglomerates	Neat cement, cementitious, concrete
Fractured, crevised, jointed, or cavernous limestone	Neat cement, cementitious, mix cementitious and clean peastone, layered combination of cementitious or neat cement with bentonite chips or clean peastone aggregate
Flowing artesian groundwater, methane or other subterranean gas, or groundwater with total hardness over 500 milligrams per liter (mg/l) or chloride over 1,500 mg/l	Neat cement, cementitious concrete

To avoid damage or leakage of the heat transfer fluid into the surrounding soil, the CSA C448-16 standard for subterranean polyethylene pipes should be followed. The same standards are to be followed should antifreeze, inhibitors, grouts, drilling fluids, or additives (including sand) be added to the heat transfer fluid (CSA C448-16).

9.3.2. Heat transfer fluids

According to the CSA-C448 Standards regarding the design and installation of ground source heat exchanger, in the case of heat transferring fluids, the most common place acceptable fluids for geothermal heat exchange include, but are not limited to, ethanol, propylene glycol, and methanol solutions (CSA C448-16). Due to the potential for risks to costs, human health, and environmental risks, these are all dependent on the authority having jurisdiction. The table in the annex G indicates the most common heat exchanging fluids for geothermal use and their associated risks. Heat transfer fluids should be selected by a professional contractor and installer specialized in geothermal heating systems (CSA C448-16).

9.4. Operation

9.4.1. Maintenance

Once geothermal heating units are installed, they require yearly maintenance and inspections by professional and competent service contractors. This is done not only to determine the operational health and efficiency of the system by also to ensure that there has been no damage sustained by the system that may lead to environmental or human health hazards. These inspections also help prevents unexpected costs to maintenance and cleanup from the system.

9.5. End of life

9.5.1. Decommissioning

In the event that a vertical closed loop is leaking or is no longer in use, it should be decommissioned by flushing the heat exchange fluid with air and by completely filling the loop with grouting material (STEP, 2017). Prior to decommissioning, the owner or decommissioning company must have the necessary permits in order to properly decommission or abandon a borehole and to adequately handle and dispose of the heat transfer fluid.

10.0 Environmental risks

In a project of such a scale, there is a possibility for there to be environmental risks. In order to prevent these risks, it is important to understand what they are and what possible mitigations must be taken in the event of one or more happening.

10.1. Groundwater and Soil Contamination

Contamination to the soil or groundwater surrounding the system can cause serious damage to both the environment and human health. Therefore, the CSA C448-16 standards concerning heating fluids that are safe for use in geothermal heaters should be consulted. The same standard applies when it comes to the selection of pipe configuration, attachment, material and size, and installment.

During drilling or excavation, the drilling mud should not be of a type that could serve as a nutrient to subsurface microorganisms. Potential nutrient sources should be flushed/removed to avoid growth of bacteria, pathogens, and other viral species (CSA C448-16).

10.2. Groundwater and Soil Temperature

The microorganisms in the groundwater and soil should be investigated to ensure that pathogens are not encouraged to multiply due to changing temperatures surrounding the pipes.

Ground temperatures should not adversely affect surrounding habitats and soil stability of surrounding buildings and structures (CSA C448-16).

10.3. Damage and Remediation to Excavated Site

In the case of most geothermal heating systems, the area of land required is negligible due to the configuration and depth of the pipes. However, in the case of a large-scale project or a horizontal loop, the land required is very large and therefore some ecosystems may be at risk during the construction process. Therefore, a survey of the surrounding ecosystem should be done prior to the excavation in order to determine whether relocation or remediation of the ecosystem would be possible.

11.0 Safety and Ergonomics

11.1. Risk Assessment

The following table explains the possible environmental, human and material risks, their weight and how to avoid or mitigate them.

Table 16. Risk assessment and mitigation measures.

Risk	Scale	Cause	Mitigation
Overheating of the pump	1	Mechanical malfunction	Proper maintenance of the system
Pipe breaking	2	Rocks, frozen lumps, refuse or other large objects in the backfilling material	Backfilling material should be verified.
Frost damage	2	Heaving Liquid freezes in the pipes	Build below the frost line and put an antifreeze that follows the CSA C448-16 standard in the liquid.
Injury during the installation/maintenance	2	Dangerous behaviours on the construction site	Make sure the Code national des bâtiments agricoles as well as the CSST standards are followed.
Soil/groundwater contamination	3	Leakage from the pipes	Follow the CSA C448-16 standard concerning the liquids that can be used and the pipes.

11.2. Construction

In order to prevent injury or jeopardize the construction process, a verification sheet would be used in the excavation of the project. A list provided by the "Code de sécurité pour les travaux de construction" and the "Loi sur la santé et la sécurité du travail" should be consulted before, during, and after the excavation (CNESST, 2013). This includes following the "Régie du Bâtiments" guide from la "Commission de la santé et de la sécurité du travail (CSST)" on safety during excavation work (CNESST, 2013). In the case of this design, this especially includes being mindful of existing structures above and below ground. These include electrical lines, gas pipes, water pipes, other buildings, and trees (CNESST, 2013). Further damage to equipment or essential service lines may cause a delay in the operation and make installation more expensive.

Other applicable safety codes that should be included are the “Code national des bâtiment agricoles” and APSAM.

11.3. Operation

The design must be simple to use. An instruction manual as well as training should be issued to the client so that operations may be made simpler and safer.

11.4. Maintenance

As mentioned, due to the cost of drilling and excavation being high in Quebec, maintenance on the buried system should be done as infrequently as possible. Should maintenance be required, recovery of the pipes should be as easy as possible to avoid high maintenance costs and risk of injury. However, maintenance of the heat pumps should be done regularly by trained professionals.

11.5. Risks associated with Failure

Damages associated to pipes rupturing can be the cause of rocks, frozen soil clumps, or refuse. When backfilling one must pay special attention when dealing with these materials and backfilling materials should first be verified (CSA C448-16).

Frost heaving can lead to failure both in the inner fluid freezing or by frost heaving action. To avoid damages and associated maintenance costs, the system should be installed below the frost line of the region, which can be found by following the standards provided by APSAM (APSAM, 2019).

Material selection should be done according to standards such as the CSA C448-16 in order to meet system specification and requirements.

11.6. Expertise

Most, if not all, the expertise in Quebec regarding ground heat exchangers is directed toward residential use. This makes it difficult to get accurate information for the specific case of greenhouses.

12.0 Social impacts

As far as fossil fuels are concerned, according to Érika Bouchard, propane is a relatively stable fuel source for heating when compared to coal or oil. However, the future of propane as a reliable heating source is still uncertain, not only for crops but also for post-harvest drying, but also for livestock, poultry, and people. An example of this uncertainty in this fuel source - and to an extent the importance of it to Quebec agriculture - can be seen in the recent propane shortage that hit the province in the fall of 2019 which left many producers with not enough propane to operate their businesses (Montreal Gazette, 2019).

Faced with this uncertainty and the evidence provided, it is possible that geothermal heating could help provide both farmers and residents with a constant and reliable supply of heat without having to rely on external fuel sources. This along with the peace of mind of knowing that the source of heating is also eco-friendly and virtually emission free can help geothermal energy become more widely adopted in the agricultural sector in Quebec.

13.0 Future recommendations

13.1. Expansion

The current geothermal takes into account the construction of a new greenhouse and the phases in which the construction will take place. As previously mentioned, the project is separated into two initial phases and a third phase planned for the future. In planning for geothermal systems, like in planning for land use for a farm, it is wise to plan in advance to take into account the needs of the expanded project. In the case of this design, the size and specifications of the greenhouse's expansion was given and therefore was able to be taken into account in the initial design of the heating system. Furthermore, vertical closed-loop geothermal systems like the one proposed can be easily expanded to meet higher heat demands.

13.2. Cooling potential

One of the many attractive qualities of geoexchange technology is the potential for it to be used for both heating and cooling (NRCAN, 2004). The cooling cycle, in the case of geoexchange, is basically the reverse of the heating cycle. This is done by reversing the direction of the refrigerant flow by the reversing valve (NRCAN, 2004). This means that rather than picking up heat from the earth and transferring it through the building, the system picks up hot air from the building and passes the now warmer refrigerant through the cool and constant earth before being returned as cool air to the building (NRCAN, 2004). Using a geothermal heating system in tandem as a cooling system, especially in the case of a greenhouse which requires constant temperature monitoring in the summer as in the winter, can prove to not only be a sound solution in efficiency but also in savings, as it would help lower the cost in cooling measures taken by farm owners and operators (e.g. the electricity required to be constantly running fans and sprayers as well as the periodic costs due to repairing these systems) (NRCAN, 2004).

14.0 Conclusion

The future of Quebec agriculture will see more and more farmers farming crops year-round in greenhouses. In order to operate their business, farmers will have to find a reliable source of heat. As well as being reliable, this source of heat must be economically viable, environmentally sustainable, and socially acceptable. When compared with current heating systems that rely heavily on electricity or fossil fuels, geothermal heating not only meets all three of these criteria but surpasses them in many ways.

To conclude, we are hopeful that geothermal technologies will become more utilized and accepted as a sustainable heat source not only for Quebec agribusinesses and homes, but across Canada and the globe. The future of Quebec agriculture is in truly green greenhouses.

References

APSAM. (2019). Profondeurs de protection contre le gel. Association paritaire pour la santé et la sécurité du travail, secteur « affaires municipales ». Retrieved from https://www.apsam.com/clientele/cols-bleus/aqueduc-et-egouts/degel-des-tuyaux/profondeurs-de-protection-contre-le-gel

Beaudry, C., Malet, X., Lefebvre, R., Rivard, C. (2011). Délimitation des eaux souterraines saumâtres en Montérégie Est, Québec, Canada. *Commission géologique du Canada.* Dossier publique (6960). http://ftp.maps.canada.ca/pub/nrcan_rncan/publications/ess_sst/289/289123/of_6960.pdf

CanSIS. (2012). Soil Survey Reports for Quebec. Canadian Soil Information Service. Retrieved from http://sis.agr.gc.ca/cansis/publications/surveys/pq/index.html

CGEC. (2010). The State of the Canadian Geothermal Heat Pump Industry 2010. Montreal, QC. Retrieved from http://www.geo-exchange.ca/en/UserAttachments/article64_Industry%20Survey%202010_FINAL_E.pdf

CGEC. (2019). Geothermal Energy. Canadian GeoExchange Coalition. Retrieved from http://www.geo-exchange.ca/en/geoexchange_systems_design_faq4.php

Climate Change Canada. (2019). Canadian Climate Normals 1981-2010 Station Data. Retrieved from http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnProx&txtRadius=25&optProxType=city&selCity=45|31|73|39|Montréal&selPark=&txtCentralLatDeg=&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongDeg=&txtCentralLongMin=0&txtCentralLongSec=0&stnID=5415&dispBack=0

CNESST. (2013). Pour mieux exécuter les travaux de creusement, d'excavation et de tranchée. Commission des normes, de l'équité, de la santé et de la sécurité du travail. Retrieved from https://www.cnesst.gouv.qc.ca/publications/200/Documents/DC200_2301web.pdf

CRAAQ (2017). Serre - Coûts de construction - Septembre 2017. PREF0005. Centre de Référence en Agriculture et Agroalimentaire du Québec.

CRAAQ. (2008). Énergies alternatives durable en milieu agricole. Centre de Référence en Agriculture et Agroalimentaire du Québec. Retrieved from https://www.agrireseau.net/documents/74700/energies-alternatives-durables-en-milieu-agricole

CSA. (2016). C448 Series-16: Design and installation of ground source heat pump systems for commercial and residential buildings. Canadian Standard Association. Toronto, ONT: CSA

Engineering ToolBox, (2003). *Heat Loss from Buildings*. Retrieved from: https://www.engineeringtoolbox.com/heat-loss-buildings-d_113.html

Environment Quality Act. Chapter Q-2, r. 35.2. Retrieved from http://legisquebec.gouv.qc.ca/en/ShowDoc/cr/Q-2,%20r.%2035.2

EPA. (2016). Greenhouse gas inventory guidance: Direct emissions from stationary combustion sources. United-States environmental protection agency. Retrieve from https://www.epa.gov/sites/production/files/2016-03/documents/stationaryemissions_3_2016.pdf

GDA. (2019). Gobeil Dion & Associés Inc. Retrieved from https://www.gobeildion.com/

Hofstrand, D. (2008). Liquid fuel measurements and conversions. Iowa State University. Retrieved from https://www.extension.iastate.edu/agdm/wholefarm/html/c6-87.html

Hydro-Quebec. (2019). Geothermal systems. Retrieved from http://www.hydroquebec.com/residential/energy-wise/windows-heating-air-conditioning/geothermal-systems.html

Hydro-Québec. (2019). GHG emissions and Hydro-Québec electricity. Retrieved from https://www.hydroquebec.com/sustainable-development/specialized-documentation/ghg-emissions.html

Hydro-Québec. (2019). Mieux consommer: systèmes géothermiques. Retrieved from : http://www.hydroquebec.com/residentiel/mieux-consommer/fenetres-chauffage-climatisation/geothermie.html

IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/ar4/syr/

L.-M. Dion, M. Lefsrud. (2010). Biomass Heating for Improved Greenhouse Efficiency. *Quebec Farmers' Advocate*. Retrieved from https://www.mcgill.ca/biomass-production-lab/files/biomass-production-lab/BiomassHeatingForIncreasedGreenhouseEfficiency.pdf

LEED. (2019). Leadership in Energy and Environmental Design. Retrieved from https://new.usgbc.org/leed

Lund, J., Chiasson, A., Boyd, T. (2006). Oregon Institute of Technology (Geo-Heat Center). Retrieved from https://www.oit.edu/docs/default-source/geoheat-center-documents/toa/winnebago-life-cycle-cost-analysis-report.pdf?sfvrsn=6

Ma, G., Chai, Q. (2004). Characteristics of an improved heat-pump cycle for cold regions. *Applied Energy,* 77(3), 235-247. https://doi.org/10.1016/S0306-2619(03)00123-5

Michigan DNRE. (2010). Best Practices for Geothermal Vertical Closed-Loop Installations. Michigan Department of Natural Resources and Environment (Groundwater division). Retrieved from https://www.michigan.gov/documents/mpsc/geo_best_practises_327048_7.pdf

Montreal Gazette and Presse Canadienne**.** (2019). As propane shortage worsens, Quebec farmers push for end to CN strike. Montreal Gazette. Retrieved from https://montrealgazette.com/news/local-news/as-propane-shortage-worsens-quebec-farmers-push-for-end-to-cn-strike

NASA. (2013). Carbon dioxide. National Aeronautics and Space Administration. Retrieved from www.climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide/

NGWA. (2019). How much water does an open-loop geothermal heat pump system require?. The groundwater association. Retrieved from https://wellowner.org/geothermal-heat-pumps/q-how-much-water-does-an-open-loop-geothermal-heat-pump-system-require/

NIH. (2013). Geothermal or ground source heat pumps part II: costs and design considerations. National institutes of health, division of technical resources. Issue 19. Retrieved from: https://www.orf.od.nih.gov/PoliciesAndGuidelines/Documents/Technical%20Bulletins/Ground%20Source%20Heat%20Pumps%20Part%20II%20Costs%20and%20Design%20Considerations%20August%202013%20Bulletin_508.pdf

Norex. (2013). Panneau architectural à âme de polianurate. Retrieved from http://www.producetech.com/img/pdf/Francais/Norbec/NORBEC%20-%20PANNEAU%20ISOLANT%20EN%20POLYUR%C3%89THANE.pdf

NRCAN. (2004). Heating and cooling with a heat pump. Natural Resources Canada. Retrieved from https://www.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/pdf/publications/infosource/pub/home/heating-heat-pump/booklet.pdf

NRCAN. (2017). Ground source heat-pumps (earth-energy system). Natural resources Canada. Retrieved from: https://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6833

NRCAN. (2018a). Energy and Greenhouse Gas Emissions (GHGs). Natural Resources Canada. Retrieved from www.nrcan.gc.ca/energy/facts/energy-ghgs/20063

NRCAN. (2018b). Financial incentives by province. Natural Resources Canada. Retrieved from https://www.nrcan.gc.ca/energy/funding/efficiency/4947

Omer, A. M. (2008). Ground-source heat pumps systems and applications. *Renewable and sustainable energy reviews,* 12(2), 344-371. https://doi.org/10.1016/j.rser.2006.10.003

Proulx-Gobeil, G., Dion, L.-M. (2015). Évaluation du chauffage à l'électricité pour les serres. Gobeil Dion & Associés inc. Retrieved from https://www.agrireseau.net/documents/Document_91386.pdf

PSQ. (2017). D'hier à aujourd'hui – la serriculture au Québec. Les Producteurs en Serres du Québec Retrieved from https://www.serres.quebec/historique/

Rafferty K.D. (1997). Chapter 14: Greenhouses. In *Ground-source heat pump: design of geothermal systems for commercial and institutional buildings.* (pp. 307 – 326). ASHRAE books

Self, S. J., Reddy, B. V., Rosen, M. A. (2013). Geothermal heat pump system: status review and comparison with other heating options. *Applied Energy*, 101, 341-348. https://doi.org/10.1016/j.apenergy.2012.01.048

SIGÉOM. (2019). Système d'Information Géominière du Québec. Interactive map. Department of natural resources and energy of Quebec. Retrieved from http://sigeom.mines.gouv.qc.ca/signet/classes/I1108_afchCarteIntr

Sircar, A., Yadave, K., Sahajpal, S. (2016). Overview on direct application of geothermal energy. *International advanced research journal in science, engineering and technology,* 3(9). DOI: 10.17148/IARJSET.2016.3925

STEP. (2017). Geothermal Feasibility Assessments: Guidance for Prospective System Owners. Sustainable Technologies Evaluation Program Toronto and Region Conservation. Retrieved from https://sustainabletechnologies.ca/app/uploads/2017/10/Final-Geothermal-Feasibility-Tech-Brief-10032017.pdf

The Globe and Mail. (2019). Canada's carbon tax: A guide to who's affected, who pays what and who opposes it. Retrieved from https://www.theglobeandmail.com/canada/article-canadas-carbon-tax-a-guide/

Ville de Cowansville. (2017a). Demande de permis de construire: Agrandissement & Transformation. Retrieved from http://www.ville.cowansville.qc.ca/webconcepteurcontent63/000024400000/upload/Depliant-Demandedepermisdeconstruire-Agrand.&Transf.-Oct17.pdf

Ville de Cowansville. (2017b). Contrôle de l'érosion et la gestion des eaux de ruissellement. Retrieved from http://www.ville.cowansville.qc.ca/webconcepteurcontent63/000024400000/upload/Depliant-Controledel'erosioneteauxderuissellement-Oct17.pdf

Ville de Lac Brome. (2013). Règlements sur les permis et certificats. Retrieved from https://ville.lac-brome.qc.ca/download/reglements_urbanisme_et_environnement/Permis-et-certificats-599.pdf

Yang, H., Cui, P., Fang, Z. (2010). Vertical-borehole ground-coupled heat pumps: A review of models and systems. *Applied energy*, 87(1), 16-27. https://doi.org/10.1016/j.apenergy.2009.04.038

Yang, W., Shi, M., Liu, G., Chen, Z. (2009). A two-region simulation model of vertical U-tube ground heat exchanger and its experimental verification. *Applied Energy*, 86(10), 2005-2012. https://doi.org/10.1016/j.apenergy.2008.11.008

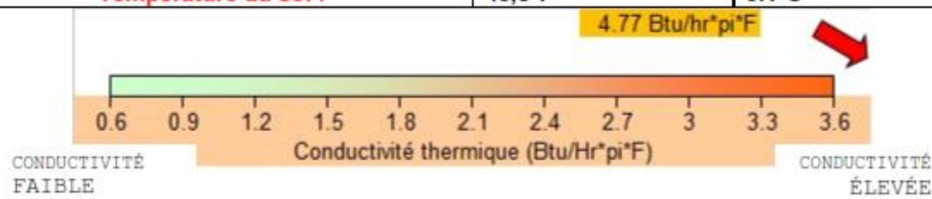
Younger, P., (2015). Geothermal energy: delivering on the global potential. *Energies,* 8(10), 11737-11754. https://doi.org/10.3390/en81011737

Annex A:

Puits Bernier Ground Characteristics of Other Projects In The Area

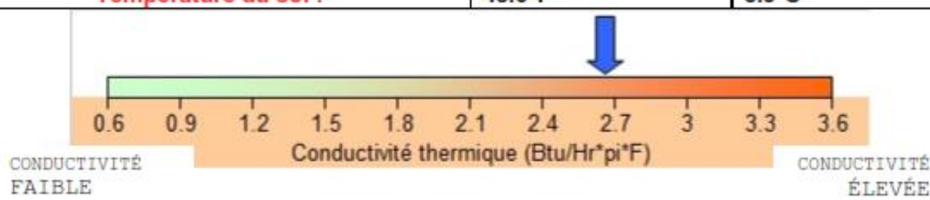
Résultat d'un projet à Mercier

Conductivité mesurée :	4.77 BTU/hr-pi-°F	8.26 W/ (m*k)
Diffusivité :	2.78 pi^2/jour	0.258 m^2/jour
Température du sol :	48,5°F	9.1^0C



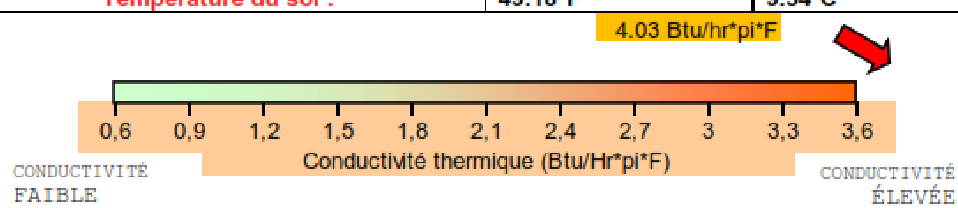
Résultat d'un projet à St-Remi

Conductivité mesurée :	2.63 BTU/hr-pi-°F	4.68 W/ (m*k)
Diffusivité :	1.62 pi^2/jour	0.150 m^2/jour
Température du sol :	48.0°F	8.9^0C



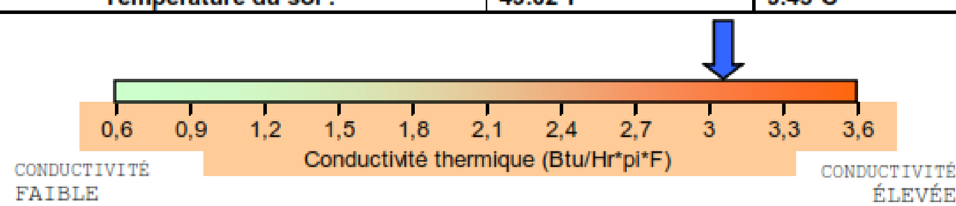
Projet à Ste- Clotilde

Conductivité mesurée :	4.03 BTU/hr-pi-°F	6.97 W/ (m*k)
Diffusivité :	2.41 pi^2/jour	0.224 m^2/jour
Température du sol :	49.18°F	9.54^0C



Projet à hemmignford

Conductivité mesurée :	3.07 BTU/hr-pi-°F	5.46 W/ (m*k)
Diffusivité :	1.85 pi^2/jour	0.172 m^2/jour
Température du sol :	49.02°F	9.45^0C



Annex B:

Plan of the proposed construction phases

Phase #1 (0.12ha)

Phase #2 (0.75 ha)
Entrepôt 365m²

Phase #3 (1.32 ha)

Phase #4 (2.61 ha)
Entrepôt 820m²

Phase #5 (5.65 ha)

Dimensions chapelles :

30’ x 204pi (restant) + 12 de couloir central

Annex C:
ASHRAE Climatic Data For Frelighsburg, Qc

FRELIGHSBURG, QC, Canada

WMO#: **713730**

Lat: **45.030N** Long: **72.850W** Elev: **224** StdP: **98.66** Time Zone: **-5.00 (NAE)** Period: **93-14** WBAN: **99999**

Annual Heating and Humidification Design Conditions

	Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		
				99.6%			99%			0.4%		1%				
		99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	
(1)	1	-24.7	-21.5	-29.7	0.2	-24.1	-26.4	0.3	-20.9	8.7	-4.3	7.9	-4.4	2.0	270	(1)

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

	Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
			0.4%		1%		2%		0.4%		1%		2%				
			DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(2)	7	9.6	29.4	21.8	27.9	21.1	26.5	20.2	23.4	27.5	22.4	26.2	21.5	25.1	2.8	240	(2)

	Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Extreme Max WB	
	0.4%			1%			2%			0.4%		1%		2%			
	DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(3)	22.1	17.2	25.8	21.1	16.2	24.6	20.2	15.2	23.8	71.0	27.9	66.9	26.2	63.6	25.1	27.5	(3)

Extreme Annual Design Conditions

	Extreme Annual WS				Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature								
					Mean		Standard Deviation		n=5 years		n=10 years		n=20 years		n=50 years		
	1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	(n)	(o)	(p)		(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	
(4)	7.3	6.3	5.5	DB	-29.2	32.1	4.3	1.3	-32.3	33.0	-34.8	33.7	-37.2	34.5	-40.4	35.4	(4)
(5)				WB	-29.3	25.5	4.2	1.1	-32.3	26.3	-34.7	27.0	-37.0	27.6	-40.0	28.4	(5)

Monthly Climatic Design Conditions

				Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
				(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(6)	Temperatures, Degree-Days and Degree-Hours	DBAvg		6.9	-8.3	-7.2	-1.6	6.2	13.1	18.1	20.4	19.4	15.3	8.8	2.7	-4.3	(6)
(7)		DBStd		11.39	7.92	6.70	6.51	5.07	4.36	3.81	2.96	3.15	4.20	4.90	5.56	6.27	(7)
(8)		HDD10.0		2331	569	481	363	137	18	0	0	0	6	84	227	444	(8)
(9)		HDD18.3		4365	827	714	618	367	172	51	13	26	109	297	469	702	(9)
(10)		CDD10.0		1213	1	0	3	22	113	242	322	292	164	47	7	0	(10)
(11)		CDD18.3		206	0	0	0	1	8	43	77	59	17	1	0	0	(11)
(12)		CDH23.3		1394	0	0	1	16	76	328	516	356	97	4	0	0	(12)
(13)		CDH26.7		276	0	0	0	2	12	76	108	62	16	0	0	0	(13)
(14)	Wind	WSAvg		2.4	2.7	2.6	2.7	2.8	2.4	2.1	2.0	1.8	2.0	2.4	2.7	2.6	(14)
(15)	Precipitation	PrecAvg		1191	83	67	79	88	104	106	117	123	111	109	103	102	(15)
(16)		PrecMax		1457	165	121	123	177	212	194	176	214	205	195	213	212	(16)
(17)		PrecMin		989	31	29	36	20	32	41	52	49	46	49	41	52	(17)
(18)		PrecStd		124	29	22	20	38	38	34	29	33	35	41	29	35	(18)
(19)	Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		13.9	10.4	19.9	25.8	28.4	31.3	31.3	30.5	29.0	23.7	18.7	11.3	(19)
(20)			MCWB		11.8	5.7	14.0	16.1	18.9	23.2	24.0	22.8	22.1	16.8	14.2	9.4	(20)
(21)		2%	DB		8.8	7.0	13.3	21.4	25.5	28.9	29.2	28.3	26.0	21.2	15.9	8.8	(21)
(22)			MCWB		6.7	4.3	8.7	13.6	16.6	21.0	22.3	21.5	20.3	15.7	12.0	6.6	(22)
(23)		5%	DB		5.1	4.5	10.1	17.8	23.1	26.9	27.8	26.8	23.9	18.7	13.7	6.2	(23)
(24)			MCWB		3.5	2.0	5.8	10.5	15.9	20.2	21.4	20.8	19.1	14.1	10.4	4.4	(24)
(25)		10%	DB		2.4	2.4	7.5	14.7	20.8	25.2	26.2	25.4	22.1	16.4	11.1	3.8	(25)
(26)			MCWB		0.8	0.4	4.5	9.0	14.7	19.1	20.5	20.1	17.8	12.8	8.4	2.0	(26)
(27)	Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB		12.0	6.9	14.7	17.5	20.6	24.3	25.2	24.2	22.9	18.5	15.3	10.0	(27)
(28)			MCDB		14.1	9.4	19.8	23.6	25.2	29.3	30.1	28.4	26.8	21.8	17.4	11.3	(28)
(29)		2%	WB		7.2	4.3	9.2	14.4	18.7	22.7	23.6	22.8	21.2	16.2	12.7	7.0	(29)
(30)			MCDB		8.3	6.5	12.5	20.0	22.8	27.1	27.5	26.5	25.0	20.0	15.1	8.3	(30)
(31)		5%	WB		3.6	2.1	6.5	11.7	17.1	21.4	22.5	21.8	19.8	14.6	10.6	4.6	(31)
(32)			MCDB		4.9	4.1	9.1	16.2	21.4	25.4	26.1	25.4	22.9	18.0	12.9	6.1	(32)
(33)		10%	WB		0.9	0.6	4.5	9.5	15.5	20.1	21.5	20.9	18.5	13.2	8.4	2.2	(33)
(34)			MCDB		2.2	2.1	7.5	13.9	19.5	23.4	25.0	24.3	21.6	15.9	10.7	3.6	(34)
(35)	Mean Daily Temperature Range		MDBR		9.1	9.3	9.1	9.9	10.3	10.0	9.6	9.7	9.7	8.4	7.5	7.5	(35)
(36)		5% DB	MCDBR		10.5	9.8	12.0	14.8	13.1	12.4	11.0	10.9	11.3	11.2	10.8	9.0	(36)
(37)			MCWBR		9.5	7.9	8.3	8.9	7.2	6.6	5.8	5.9	6.7	7.2	8.4	8.1	(37)
(38)		5% WB	MCDBR		10.4	9.1	11.1	13.0	11.1	10.4	9.4	9.6	9.8	10.2	10.0	9.1	(38)
(39)			MCWBR		9.7	7.8	8.5	8.9	6.9	6.3	5.6	5.7	6.5	7.1	8.8	8.5	(39)
(40)	Clear-Sky Solar Irradiance	taub			0.262	0.284	0.319	0.349	0.370	0.418	0.427	0.405	0.365	0.327	0.303	0.280	(40)
(41)		taud			2.380	2.306	2.357	2.393	2.390	2.252	2.233	2.291	2.396	2.510	2.497	2.382	(41)
(42)		Ebn,noon			865	902	915	912	899	852	839	845	854	848	809	796	(42)
(43)		Edh,noon			73	96	106	112	116	134	135	123	102	79	67	67	(43)
(44)	All-Sky Solar Radiation	RadAvg			1.55	2.62	3.71	4.41	5.06	5.52	5.64	5.06	3.94	2.34	1.43	1.08	(44)
(45)		RadStd			0.16	0.26	0.39	0.47	0.48	0.45	0.43	0.27	0.28	0.18	0.20	0.08	(45)

Nomenclature: See separate page

Annex D:

Peak Heat Loss Calculations

1. Phase 1: Greenhouse

Measurements and Assumptions:

Inside temperature:
- Day: 22°C
- Night: 18°C

Peak heat loss is assumed to happen at night, when the temperature is lowest and the HPS lamps are turned off.

Heating dry bulb: 99%

Extreme temperature: -21.5°C (from ASHRAE-Handbook fundamentals, 2017. Annex C)

Materials:

- Roof: Double polyethylene [Heat transfer coefficient: 3.9748 W/(m^2*°C)]
- Walls: Polycarbonate 8mm [Heat transfer coefficient: 3.5773 W/(m^2*°C)]
- Thermal screens [Heat transfer coefficient: 2.49 W/(m^2*°C)]
- Insulating panels Norex 3” (76.2mm) [Heat transfer coefficient: 0.2554 W/(m^2*°C)]

Greenhouse dimensions:

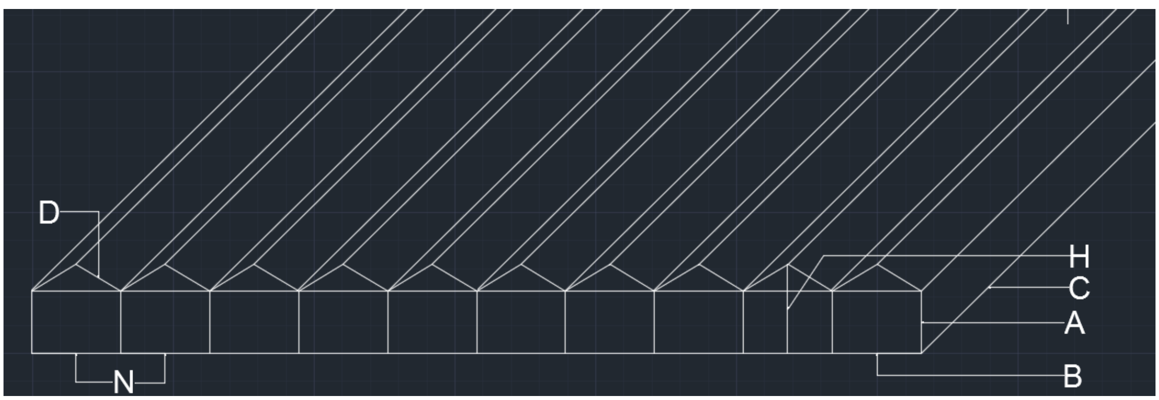


Figure 1. Dimensions of the greenhouse

A = 6.1m (20ft) C = 65.8m (216ft) H = 8.02
B = 9.1m (30ft) D = 4.9m (13.1ft) N = 10 (number of houses)
E (height of insulation wall) = 0.6m (2ft)

Calculations:

Surface Area:

Roof:

$$A_R = [2 \times (D \times C)] \times N$$
$$A_R = [2 \times (4.9 \times 65.8)] \times 10$$
$$A_R = 6\,499.1\ m^2$$

Walls:

$$A_W = 2[(N * B * (A - E)) + (C * (A - E)) + (N * \left(B * \frac{H - A}{2}\right))]$$
$$A_W = 2[(10 * 9.1 * (6.1 - 0.6)) + (65.8 * (6.1 - 0.6)) + (10 * (9.1 * (8.02 - 6.1)/2))]$$
$$A_W = 1899.52\ m^2$$

Insulation walls:

$$A_I = E * [(2 * (B * N)) + (2 * C)]$$
$$A_I = 0.6 * [(2 * (9.1 * 10)) + (2 * 65.8)]$$
$$A_I = 188.16\ m^2$$

Volume of the greenhouse:

$$V = [(A \times B \times C) + (1/3 \times B \times C \times (H - A))] \times N$$
$$V = [(6.1 \times 9.1 \times 65.8) + (1/3 \times 9.1 \times 65.8 \times (8.02 - 6.1))] \times 10$$
$$V = 40\ 357.77\ m^3$$

Heat loss:

$$Q_T = Q_C + Q_A$$

Where, Q_T: Total heat loss (W)
Q_C: Heat loss through conduction (W)
Q_A: Heat loss through natural air exchange (W)

Heat loss through conduction:

$$Q_C = U \times A \times \Delta T$$

Where, U: Heat transfer coefficient (W/(m²*°C))
A: Surface area (m²)
ΔT: Temperature difference between the inside and the outside (°C)

Roof:

$$Q_{C,R} = 3.9748 \times 6\ 499.1 \times 39.5$$
$$Q_{C,R} = 639\ 217\ W$$

Walls:

$$Q_{C,W} = 3.5773 \times 1\ 899.5 \times 39.5$$
$$Q_{C,W} = 268\ 409\ W$$

Insulation walls:

$$Q_{C,I} = 0.2554 \times 188.2 \times 39.5$$
$$Q_{C,I} = 1\ 898\ W$$

Total:

$$Q_C = Q_{C,R} + Q_{C,W} + Q_{C,I}$$
$$Q_C = 639\ 217 + 268\ 409 + 1\ 898$$
$$Q_C = 909\ 524\ W$$

Heat loss through air exchange:

$$Q_A = c_p \times \rho \times V \times \Delta T \times n$$

Where, c_p: Specific heat of air (1003 J/kg*K)
ρ: Air density at -21.5°C (1.402 kg/m³)
V: Greenhouse volume (m³)
n: Number of natural air exchange per seconds*

*The value of natural air exchange is assumed to be 0.5/h. It is also assumed that 0.5/h = 1.4×10^{-4}/s.

$$Q_A = 1003 \times 1.402 \times 40\ 357.77 \times 39.5 \times 1.4x10^{-4}$$
$$Q_A = 313\ 835\ W$$

Total heat loss:

$$Q_T = 909\ 524 + 313\ 835$$
$$Q_T = 1\ 223\ 359\ W = 1\ 223.4kW = 348 \text{ tons of heat}$$

2. Phase 2: Service Area

Measurements and Assumptions:

Inside temperature:
- Day: 22°C
- Night: 18°C

Peak power: is assumed to happen at night, when the temperature is lowest and the HPS lamps are turned off.

Heating dry bulb: 99%

Extreme temperature: -21.5°C (from ASHRAE-Handbook fundamentals, 2017. Annex C)

Materials:

- Roof: Double polyethylene [Heat transfer coefficient: 3.9748 W/(m²*°C)]
- Walls: All Norex 3" insulating panels [Heat transfer coefficient: 0.2554 W/(m²*°C)]
- Thermal screens [Heat transfer coefficient: 2.49 W/(m²*°C)]

Service area dimensions:

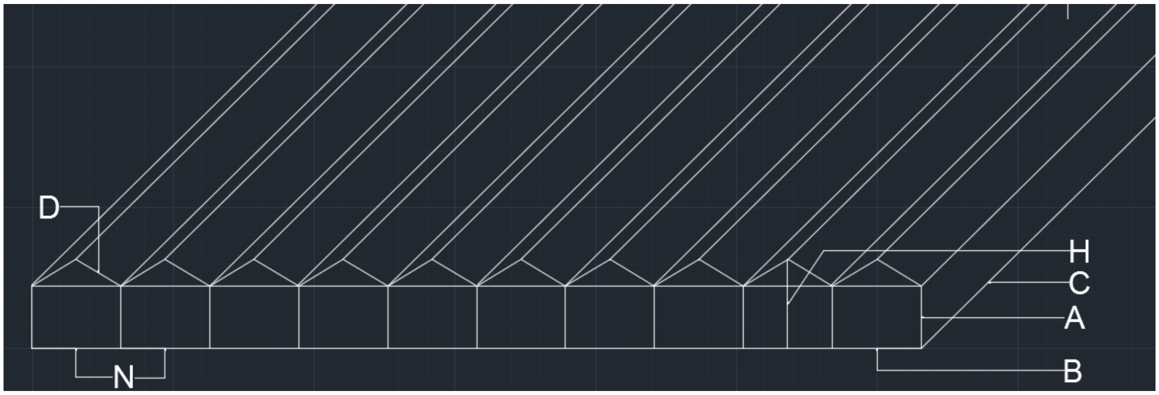


Figure 2. Dimensions of the service area

A = 6.1m (20ft)
C = 20m (66ft)
H = 8.02
B = 9.1m (30ft)
D = 4.9m (13.1ft)
N = 2 (number of houses)
E (height of insulation wall) = 6.1m (20ft)

Calculations:

Surface Area:

- Roof:

$$A_R = [2 \times (D \times C)] \times N$$
$$A_R = [2 \times (4.9 \times 20)] \times 2$$
$$A_R = 395.1\, m^2$$

- Walls:

$$A_W = 2[(N * B * A) + (C * A) + (N * \left(B * \frac{H - A}{2}\right))]$$
$$A_W = 2[(2 * 9.1 * 6.1) + (20 * 6.1) + (2 * (9.1 * (8.02 - 6.1)/2))]$$
$$A_W = 501.0 m^2$$

Volume of the greenhouse:

$$V = [(A \times B \times C) + (1/3 \times B \times C \times (H - A))] \times N$$
$$V = [(6.1 \times 9.1 \times 20) + (1/3 \times 9.1 \times 20 \times (8.02 - 6.1))] \times 2$$
$$V = 2\,453.4\, m^3$$

Heat loss:

$$Q_T = Q_C + Q_A$$

Where, Q_T: Total heat loss (W)
Q_C: Heat loss through conduction (W)
Q_A: Heat loss through natural air exchange (W)

Heat loss through conduction:

$$Q_C = U \times A \times \Delta T$$

Where, U: Heat transfer coefficient (W/(m²*°C))
A: Surface area (m²)
ΔT: Temperature difference between the inside and the outside (°C)

Roof:

$$Q_{C,R} = 2.49 \times 395.1 \times 39.5$$
$$Q_{C,R} = 38\ 858\ W$$

Walls:

$$Q_{C,W} = 0.2554 \times 501 \times 39.5$$
$$Q_{C,W} = 5\ 054\ W$$

Total:

$$Q_C = Q_{C,R} + Q_{C,W}$$
$$Q_C = 38\ 858 + 5\ 054$$
$$Q_C = 43\ 913\ W$$

Heat loss through air exchange:

$$Q_A = c_p \times \rho \times V \times \Delta T \times n$$

Where, c_p: Specific heat of air (1003 J/kg*K)
ρ: Air density at -21.5°C (1.402 kg/m³)
V: Greenhouse volume (m³)
n: Number of natural air exchange per seconds*

*The value of natural air exchange is assumed to be 0.5/h. It is also assumed that 0.5/h = 1.4x10^{-4}/s.

$$Q_A = 1003 \times 1.402 \times 2\ 453.4 \times 39.5 \times 1.4x10^{-4}$$
$$Q_A = 19\ 078\ W$$

Total heat loss:

$$Q_T = 43\ 713 + 19\ 078$$
$$Q_T = 62\ 991W = 63.0kW = 17.6 \text{ tons of heat}$$

3. Total Heat Loss for Phase 1 and 2

$$Q_T = Q_{T,Phase\ 1} + Q_{T,Phase\ 2}$$
$$Q_T = 348 + 18 = 366\ ton\ of\ heat$$

At peak demand, the maximum heat that the heating system of the greenhouse will be asked to provided is 366 ton of heat.

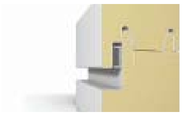
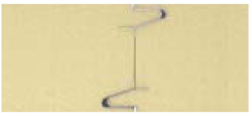
Annex E:

Norex Insulation Panels Technical Sheet

PANEL WITH POLYISOCYANURATE (POLYURETHANE) CORE

NOREX® ARCHITECTURAL PANELS ARE HIGH-ENERGY-EFFICIENT INSULATED PANELS DESIGNED FOR BUILDING ENVELOPES.

SPECIFICATIONS

	NOREX-H	NOREX-L	NOREX-S
DESCRIPTION	> Horizontal & vertical mounting > Joint with concealed fasteners > Deep fluting 3/4 in. (19mm) deep and either 3/8 in. (9.5mm) or 3/4 inch (19mm) wide > Different architectural arrangements > Applications: outdoor wall	> Vertical mounting > Joint with concealed fasteners > Applications: outdoor wall, indoor ceilings > Pressure Equalized Rainscreen Joint	> Vertical mounting with straight joint > Applications: interior partitions
WIDTH (1)(2)	24, 30, 36 or 41½ in.	24, 30, 36 or 42½ in.	44 in.
THICKNESS	2, 3 et 4 in.	2, 3, 4, 5 et 6 in.	2, 3, 4 et 5 in.
R-VALUE	R 7.41/in. (ASTM C-518 13°C- 35°C)		
LENGTH	7 to 52 ft. 3 in.		
STEEL INNER FACE	> 0.019 in. (0,483 mm) standard thickness – 26 Ga > 0.023 in. (0,584 mm) optional – 24 Ga		
STEEL OUTER FACE	0.0285 in. (0.724 mm) thickness – 22 Ga	> 0.019 in. (0.483 mm) standard thickness – 26 Ga > 0.0285 in. (0.724 mm) optional – 22 Ga	
JOINTS			

WEIGHT (3)(4)						
	Thickness (inch)	2	3	4	5	6
	Weight (lbs/ft²)	2.22	2.44	2.66	2.88	3.11

(1) The final module width may change due to variations in fabrication and installation. We do not recommend designing a panel arrangement in which the module width plays a critical role. (2) 2 in. panels are not available in 24 and 30 in. width. (3) Panel weight for a Norex-L 42½ in. wide panel. (4) Calculations based on 26 gauge steel on both sides and an insulated density of 2.65.

APPLICATIONS

Norex panels can be found in a variety of applications including industrial and commercial buildings, Cold-storage and controlled-environment buildings, Sports centers, Interior partitions and Suspended ceilings with limited load-bearing capacity.

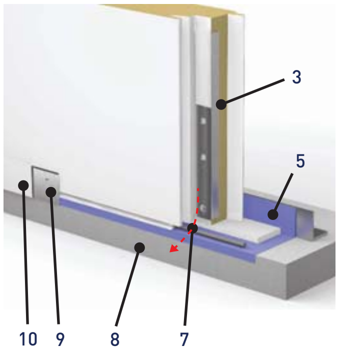
FEATURES / BENEFITS

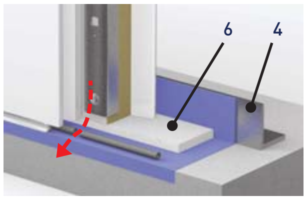
> Exclusive and superior fastening system
> Wider girt spacing reduces costs
> Fast, simple & economical installation

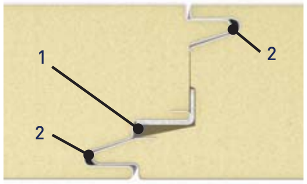
> The materials are environmentally friendly and nontoxic
> Can contribute to obtaining LEED certification for a project

> No cavities, moisture penetration, thermal bridges, risk of interstitial condensation, or lack of insulation
> Norex-L pressure-equalized rainscreen joint ensures that the building envelope is well sealed
> Factory-applied butyl joint sealer ensures maximum seal

PRESSURE-EQUALIZED RAINSCREEN JOINT







1 AIR CAVITY
2 BUTYL
3 NOREX® FASTENER
4 STRUCTURAL ANGLE
5 VAPOR BARRIER
6 POLYETHYLENE
7 WEEP HOLE
8 FOUNDATION
9 TRIM HANGER
10 TRIM

MAIN PHYSICAL PROPERTIES OF POLYISOCYANURATE

PROPERTY	METHOD	RESULTS
R Value/in. of thickness	ASTM C518	7.41
Density (lb/ft³)	ASTM D1622	Density (pcf) 2.29 Std dev 0.01
Compressive strength (psi)	ASTMD1621	13.7 PSI (3in. Thick Sample)
Flextural strength (psi)	ASTM C203	25–30
Permeability to water vapor (perms/in.)	ASTM E96/E96M	< 2,0
Water absorption (max.)	ASTM D2842	< 1.5%
Dimensional stability (max.)	ASTM 2126	Dimensional Stability Std dev 0.2 7 day Vol Chg @ 70ºC/97% R.H 4.3
Linear thermal dilation coefficient (in./in./ºF)	ASTM D696	35.47 x 10–6

TESTS

	PROCEDURE	TITLE	RESULTS
FIRE CANADA	CAN/ULC-S101	Fire endurance tests of building construction and materials	Meets 10 minutes stay-in-place requirements
	CAN/ULC-S102	Surface burning characteristics of building materials and assemblies	Meets the National Building Code of Canada requirements
	CAN/ULC-S134	Fire test of exterior wall assemblies	Complies with the fire-spread and heat-flux limitations required by the National Building Code of Canada
	CAN/ULC-S138	Fire growth of insulated building panels in a full-scale room configuration	Test requirements have been met
	S-126	Fire spread under roof deck assembly	Test requirements have been met
FIRE US	ASTM E84	Surface burning characteristics of building materials	Flame spread <25 Smoke developed <450
	FM 4880	Class 1 fire rating of insulated wall, ceiling and roof panels	Product approved
STRUCTURAL	ASTM E72	Deflexion tests of panels for building construction	See Load Chart
	FM 4881	Class 1 exterior wall structural performance	See FM Wall load Chart
AIR INFILTRATION	ASTM E283	Rate of air leakage through curtain walls under specified pressure differences	Test requirements have been met
	ASTM E330	Structural performance of exterior walls by uniform static air pressure difference	Test requirements have been met
THERMAL PERFORMANCE	ASTM C518	Steady-sate thermal transmission properties by means of heat-flow meter apparatus	R 7.41- Value 35/13°C k factor (W/m²- K/m) 19.5 R 769- Value 18/-4°C k factor (W/m²- K/m) 18.8
	CAN/ULC-S770-09	Long term thermal resistance	Testing requirements have been met per CAN/ULC-S704-11
WATER INFILTRATION	ASTM E331	Water penetration of exterior walls by uniform static air pressure differences	Test requirements have been met
	AAMA 501.1	Water penetration of exterior walls by dynamic air pressure	Test requirements have been met

Annex F:

EPA Greenhouse Gas Emissions From Stationary Combustion Sources

Emission Factors for Greenhouse Gas Inventories

Last Modified: 4 April 2014

Red text indicates an update from the 2011 version of this document.

Typically, greenhouse gas emissions are reported in units of carbon dioxide equivalent (CO_2e). Gases are converted to CO_2e by multiplying by their global warming potential (GWP). The emission factors listed in this document have not been converted to CO_2e. To do so, multiply the emissions by the corresponding GWP listed in the table below.

Gas	100-year GWP
CH_4	25
N_2O	298

Source: Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), 2007. See the source note to Table 9 for further explanation.

Table 1 Stationary Combustion Emission Factors

Fuel Type	Heating Value	CO_2 Factor	CH_4 Factor	N_2O Factor	CO_2 Factor	CH_4 Factor	N_2O Factor	Unit
	mmBtu per short ton	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per short ton	g CH_4 per short ton	g N_2O per short ton	
Coal and Coke								
Anthracite Coal	25.09	103.69	11	1.6	2,602	276	40	short tons
Bituminous Coal	24.93	93.28	11	1.6	2,325	274	40	short tons
Sub-bituminous Coal	17.25	97.17	11	1.6	1,676	190	28	short tons
Lignite Coal	14.21	97.72	11	1.6	1,389	156	23	short tons
Mixed (Commercial Sector)	21.39	94.27	11	1.6	2,016	235	34	short tons
Mixed (Electric Power Sector)	19.73	95.52	11	1.6	1,885	217	32	short tons
Mixed (Industrial Coking)	26.28	93.90	11	1.6	2,468	289	42	short tons
Mixed (Industrial Sector)	22.35	94.67	11	1.6	2,116	246	36	short tons
Coal Coke	24.80	113.67	11	1.6	2,819	273	40	short tons
Fossil Fuel-derived Fuels (Solid)								
Municipal Solid Waste	9.95	90.70	32	4.2	902	318	42	short tons
Petroleum Coke (Solid)	30.00	102.41	32	4.2	3,072	960	126	short tons
Plastics	38.00	75.00	32	4.2	2,850	1,216	160	short tons
Tires	28.00	85.97	32	4.2	2,407	896	118	short tons
Biomass Fuels (Solid)								
Agricultural Byproducts	8.25	118.17	32	4.2	975	264	35	short tons
Peat	8.00	111.84	32	4.2	895	256	34	short tons
Solid Byproducts	10.39	105.51	32	4.2	1,096	332	44	short tons
Wood and Wood Residuals	17.48	93.80	7.2	3.6	1,640	126	63	short tons
	mmBtu per scf	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per scf	g CH_4 per scf	g N_2O per scf	
Natural Gas								
Natural Gas (per scf)	0.001026	53.06	1.0	0.10	0.05444	0.00103	0.00010	scf
Fossil-derived Fuels (Gaseous)								
Blast Furnace Gas	0.000092	274.32	0.022	0.10	0.02524	0.000002	0.000009	scf
Coke Oven Gas	0.000599	46.85	0.48	0.10	0.02806	0.000288	0.000060	scf
Fuel Gas	0.001388	59.00	3.0	0.60	0.08189	0.004164	0.000833	scf
Propane Gas	0.002516	61.46	0.022	0.10	0.15463	0.000055	0.000252	scf
Biomass Fuels (Gaseous)								
Landfill Gas	0.000485	52.07	3.2	0.63	0.025254	0.001552	0.000306	scf
Other Biomass Gases	0.000655	52.07	3.2	0.63	0.034106	0.002096	0.000413	scf
	mmBtu per gallon	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu	kg CO_2 per gallon	g CH_4 per gallon	g N_2O per gallon	
Petroleum Products								
Asphalt and Road Oil	0.158	75.36	3.0	0.60	11.91	0.47	0.09	gallon
Aviation Gasoline	0.120	69.25	3.0	0.60	8.31	0.36	0.07	gallon
Butane	0.103	64.77	3.0	0.60	6.67	0.31	0.06	gallon
Butylene	0.105	68.72	3.0	0.60	7.22	0.32	0.06	gallon
Crude Oil	0.138	74.54	3.0	0.60	10.29	0.41	0.08	gallon
Distillate Fuel Oil No. 1	0.139	73.25	3.0	0.60	10.18	0.42	0.08	gallon
Distillate Fuel Oil No. 2	0.138	73.96	3.0	0.60	10.21	0.41	0.08	gallon
Distillate Fuel Oil No. 4	0.146	75.04	3.0	0.60	10.96	0.44	0.09	gallon
Ethane	0.068	59.60	3.0	0.60	4.05	0.20	0.04	gallon
Ethylene	0.058	65.96	3.0	0.60	3.83	0.17	0.03	gallon
Heavy Gas Oils	0.148	74.92	3.0	0.60	11.09	0.44	0.09	gallon
Isobutane	0.099	64.94	3.0	0.60	6.43	0.30	0.06	gallon
Isobutylene	0.103	68.86	3.0	0.60	7.09	0.31	0.06	gallon
Kerosene	0.135	75.20	3.0	0.60	10.15	0.41	0.08	gallon
Kerosene-type Jet Fuel	0.135	72.22	3.0	0.60	9.75	0.41	0.08	gallon
Liquefied Petroleum Gases (LPG)	0.092	61.71	3.0	0.60	5.68	0.28	0.06	gallon
Lubricants	0.144	74.27	3.0	0.60	10.69	0.43	0.09	gallon
Motor Gasoline	0.125	70.22	3.0	0.60	8.78	0.38	0.08	gallon
Naphtha (<401 deg F)	0.125	68.02	3.0	0.60	8.50	0.38	0.08	gallon
Natural Gasoline	0.110	66.88	3.0	0.60	7.36	0.33	0.07	gallon
Other Oil (>401 deg F)	0.139	76.22	3.0	0.60	10.59	0.42	0.08	gallon
Pentanes Plus	0.110	70.02	3.0	0.60	7.70	0.33	0.07	gallon
Petrochemical Feedstocks	0.125	71.02	3.0	0.60	8.88	0.38	0.08	gallon
Petroleum Coke	0.143	102.41	3.0	0.60	14.64	0.43	0.09	gallon
Propane	0.091	62.87	3.0	0.60	5.72	0.27	0.05	gallon
Propylene	0.091	65.95	3.0	0.60	6.00	0.27	0.05	gallon
Residual Fuel Oil No. 5	0.140	72.93	3.0	0.60	10.21	0.42	0.08	gallon
Residual Fuel Oil No. 6	0.150	75.10	3.0	0.60	11.27	0.45	0.09	gallon
Special Naphtha	0.125	72.34	3.0	0.60	9.04	0.38	0.08	gallon
Still Gas	0.143	66.72	3.0	0.60	9.54	0.43	0.09	gallon
Unfinished Oils	0.139	74.54	3.0	0.60	10.36	0.42	0.08	gallon
Used Oil	0.138	74.00	3.0	0.60	10.21	0.41	0.08	gallon
Biomass Fuels (Liquid)								
Biodiesel (100%)	0.128	73.84	1.1	0.11	9.45	0.14	0.01	gallon
Ethanol (100%)	0.084	68.44	1.1	0.11	5.75	0.09	0.01	gallon
Rendered Animal Fat	0.125	71.06	1.1	0.11	8.88	0.14	0.01	gallon
Vegetable Oil	0.120	81.55	1.1	0.11	9.79	0.13	0.01	gallon
	mmBtu per gallon	kg CO_2 per mmBtu	g CH_4 per mmBtu	g N_2O per mmBtu				
Steam and Hot Water								
Steam and Hot Water		66.33	1.250	0.125				mmBtu

Source:

Solid, gaseous, liquid and biomass fuels: Federal Register (2009) EPA; *40 CFR Parts 86, 87, 89 et al; Mandatory Reporting of Greenhouse Gases; Final Rule*, 30Oct09, 261 pp. Tables C-1 and C-2 at FR pp. 56409-56410. Revised emission factors for selected fuels: Federal Register (2010) EPA; 40 CFR Part 98; Mandatory Reporting of Greenhouse Gases; Final Rule, 17Dec10, 81 pp. With Amendments from Memo: Table of Final 2013 Revisions to the Greenhouse Gas Reporting Rule (PDF) to 40 CFR part 98, subpart C: Table C–1 to Subpart C—Default CO2 Emission Factors and High Heat Values for Various Types of Fuel and Table C–2 to Subpart C—Default CH4 and N2O Emission Factors for Various Types of Fuel.

Steam and Hot Water: EPA (2008) *Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance - Indirect Emissions from Purchases/Sales of Electricity and Steam*. Assumption: 80% boiler efficiency and fuel type assumed natural gas. Factors are per mmBtu of steam or hot water purchased.

http://www.epa.gov/ghgreporting/documents/pdf/2013/documents/memo-2013-technical-revisions.pdf

http://www.epa.gov/ghgreporting/reporters/subpart/c.html

Annex G:

Benchmarking Of Heat Transfer Fluids For Vertical Closed Loop Heat Exchangers

Table 2
Heat transfer fluids

(See Clauses 5.7.1.1.6 of ANSI/CSA C448.0, 7.4 of ANSI/CSA C448.4, and 7.6.1 of ANSI/CSA C448.5.)

Category	Methanol	Ethanol	Propylene glycol	Potassium acetate	CMA	Urea
Life cycle cost	◊◊◊	◊◊◊	◊◊[1]	◊◊[1]	◊◊[1]	◊◊◊
Corrosion	◊◊[2]	◊◊[3]	◊◊◊	◊◊	◊◊[4]	◊[5]
Leakage	◊◊◊	◊◊[6]	◊◊[6]	◊[6]	◊[8]	◊[9]
Health hazard risk	◊[10,11]	◊◊[10,12]	◊◊◊[10]	◊◊◊[10]	◊◊◊[10]	◊◊◊[10]
Fire risk	◊[13]	◊[13]	◊◊◊[14]	◊◊◊	◊◊◊	◊◊◊
Environmental risk	◊◊[15]	◊◊[15]	◊◊◊	◊◊[15]	◊◊[15]	◊◊◊
Risk of future use	◊[16]	◊◊[17]	◊◊◊	◊◊[18]	◊◊[19]	◊◊[19]

Note: *Reprinted by permission from ASHRAE Research Project RP-908 Final Report "Assessment of Antifreeze Solutions for Ground-Source Heat Pump Systems", E.W. Heinonen and R.E. Tapscott. Copyright 1996 ASHRAE, www.ashrae.org.*

Key:
◊ Potential problems, caution in use required
◊◊ Minor potential for problems
◊◊◊ Little or no potential for problems

Category	Notes
Life cycle cost	1. Higher than average installation and energy costs.
Corrosion	2. High black iron and cast iron corrosion rates. 3. High black iron and cast iron, copper and copper alloy corrosion rates. 4. Medium black iron, copper and copper alloy corrosion rates. 5. Medium black iron, high cast iron, and extremely high copper and copper alloy corrosion rates.
Leakage	6. Minor leakage observed. 7. Moderate leakage observed. Extensive leakage reported in installed systems. 8. Moderate leakage observed. 9. Massive leakage observed.
Health hazard risk	10. Protective measures required with use. See MSDS. 11. Prolonged exposure can cause headaches, nausea, vomiting, dizziness, blindness, liver damage, and death. Use of proper equipment and procedures reduces risk significantly. 12. Confirmed human carcinogen.
Fire risk	13. Pure fluid only. Little risk when diluted with water in anti-freeze. 14. Very minor potential for pure fluid fire at elevated temperatures.
Environmental risk	15. Water pollution risk.
Risk of future use	16. Toxicity and fire concerns. Prohibited in some locations. 17. Toxicity, fire, and environmental concerns. 18. Potential leakage concerns. 19. Not currently used as GSHP anti-freeze solutions. May be difficult to obtain approval for use.

5.7.1.1.7

The heat-transfer fluid shall ensure freeze protection to at least 5 °C (9 °F) below the minimum loop design temperature.