Design and Assessment of a Geothermal Greenhouse in Northern Manitoba

Sponsoring Company: KGS Group

MECH 4860 – Engineering Design – Team 3

Primary Contact: Rob Sinclair, P.Eng.

Advisor: Dr. Sean O'Brien, P.Eng.

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Date of Submission: December 8th, 2021

Letter of Transmittal

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December 8, 2021

Dr. Paul Labossiere, P.Eng.,
Associate Dean (Design Education)
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Winnipeg, MB, R3T 5V6

Dear Dr. Labossiere,

Team 3 is pleased to present the Final Design Report for the Design and Assessment of a Geothermal Greenhouse in Northern Manitoba for the MECH 4860 – Engineering Design course.

The report begins with discussing the objectives needs and target specifications for the greenhouse design. A summary of the project definition, concept generation and concept selection stages are then discussed.

The final design is presented complete with a figure of the facility layout, analytical and numerical analyses, cost analysis, bill of materials (BOM) and suggestions for future work.

Team 3 would like to thank you for all your support. Feel free to contact us for any questions or concerns you have with the contents found in this report.

Sincerely,

Jason Chartrand

Vince Harbottle

Levi Swaine

Shawn Ramos

Letter of Transmittal

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December 8, 2021

Rob Sinclair, P. Eng.,
Engineering Specialist Advisor
KGS Group
865 Waverley St., 3rd Floor
Winnipeg, MB, R3T 5P4

Dear Rob Sinclair,

Team 3 is pleased to present the Final Design Report for the Design and Assessment of a Geothermal Greenhouse in Northern Manitoba for the KGS Group.

The report begins with discussing the objectives needs and target specifications for the greenhouse design. A summary of the project definition, concept generation and concept selection stages are then discussed.

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Executive Summary

This report outlines a feasibility study for a geothermal greenhouse for northern Manitoba communities. Currently, there is a lack of access to low-cost high-quality food in northern Manitoba communities thus leading to health issues for residents of these communities. The goal of this project was to provide a sustainable solution to this lack of healthy food by designing a greenhouse using a geothermal system as its primary heating source. A cost analysis, bill of materials, installation schedule and heating simulations using COM SOL will be provided in this report.

Shamattawa First nations was determined to be a strong candidate for a geothermal greenhouse. Due to its location, the food cost in Shamattawa First nation are nearly 4 times higher on average when compared to Winnipeg. There is also no access to grid and all the main source of electricity in Shamattawa First Nations comes from a local diesel generating station with cost of $0.60 per kw/h. This combined with an issue with obesity and diabetes in the community made Shamattawa First Nation a prime candidate for the geothermal greenhouse.

The greenhouse will be 500 m^2 and will be 10x50m. The greenhouse will have 40% of the area allocated to a community area and the 60% allocated for growing. This was determined through an analysis of the required area for growing as well as determining efficient dimensions to reduce the heat loss to the surrounding areas. The greenhouse will have a full glass south facing wall at an angle of 70° and a retractable thermal blanket to maximize the solar heat gain and reduce heat loss at night. A steel frame with an OC of 6250mm combined with insulated metals panels for the siding and roof. The combination of these dimension and materials result in a well-insulated structure resulted in a net positive heat gain for all months of the year except December and January. The total energy requirement for the greenhouse was estimated to be 529 kWh per day. To achieve this necessary energy load, a 102 Hanwha Solar Canada HSC-250-60P solar panels and 10 Anorra 48 wind turbines were sourced. Three TROES 50kW,220kWh Indoor Cabinets were source to store energy for instances where there is not energy being harvested by the solar and wind.

The greenhouse will utilize a horizontal closed loop geothermal system as its primary source of heating. The geothermal system will have 2700m of piping at a depth of 20ft and 25ft to meet the required heating loads and preventing the pipes from freezing. The use of Two WaterFurnace 7 Series 700A11 Heat Pumps to achieve a max heat pump capacity of 48000 BTU/hr.

The total cost the greenhouse was estimated to be $1854210.00 CAD without taxes. It was determined that utilizing a geothermal system to heat a greenhouse in northern Manitoba is feasible. However, to determine if a geothermal greenhouse is a solution to lack of healthy food, community input will be required as well as a more detailed design and more in-depth cost analysis to determine if the greenhouse is economically feasible.

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1. Introduction

The KGS Group is a multi-disciplinary engineering consulting firm based out of Winnipeg and has offices in Regina, Thunder Bay and Mississauga. The KGS Group provides services related to engineering and geology for government and private sector projects across Canada. The KGS Group offers services from the beginning of a project all the way to implementation.

1.1 Problem Statement

Food cost, access to high quality food and high carbon emissions from food production in northern communities have created a need for a more efficient food production alternative. The lack of access to low-cost high-quality food leads to additional issues such as health concerns for the residents, and the financial constraints of high food costs. If found to be a viable solution these issues could be resolved with a renewable energy greenhouse local to the northern communities.

1.2 Objectives

The objective of this project was to provide our client, KGS Group, with a viable design concept for a geothermal greenhouse that will be located within a community of northern Manitoba. The main goal of the project for Team 3 was to determine if a geothermal greenhouse in northern Manitoba would be feasible. The design could then be presented to Health Canada to propose the geothermal greenhouse as a potential project to improve the health of northern community members. The deliverables requested by the KGS group included:

- Flow and heat transfer simulation of an effective and sustainable geothermal greenhouse, using COMSOL Multiphysics software
- The facility layout for our design
- Bill of materials (BOM)

- An installation schedule for the project
- Cost analysis
- A proposal for future work on the project; potential jobs, building maintenance considerations, and possible expansion projects.

Our geothermal greenhouse design aims to accommodate adequate temperatures, and air quality conditions, for agriculture and plant growth. The temperature ranges, as well as air quality, inside of the greenhouse will remain consistent throughout all seasons of the year (despite large fluctuations in seasonal temperatures/humidity levels outside). Carbon emissions, and other harmful processes to the environment, will be excluded and mitigated within the design as much as possible, while maintaining the agricultural effectiveness of the greenhouse. For this project to appeal to Health Canada, as a feasible government project, cost-efficiency was considered. All costs associated with the facility's location (transportation), layout, materials, and construction processes were taken into consideration. Operations of the greenhouse are planned to be suitable enough to provide both future employment as well as community involvement. The facility will be safe to work in and structurally maintainable. While it is the objective of this greenhouse to provide healthy food to remote communities, it is also aimed at promoting stronger community and potential for infrastructure expansion.

1.3 Needs and Specifications

The list of needs of the greenhouse ranked in terms of importance are itemized below and have been approved by our primary contact at the KGS Group, Rob Sinclair, P.Eng.

1. The greenhouse is safe to occupants
2. The greenhouse operates in Manitoba's harsh temperatures
3. The greenhouse operates in Manitoba's weather conditions
4. The greenhouse is used to grow plants year round
5. Greenhouse is interactive and community based
6. The greenhouse is economically viable
7. The greenhouse is environmentally friendly
8. The greenhouse must be an appropriate size

9. The greenhouse is comfortable to work in
10. The greenhouse can operate for at least 20 years

The most important need of the greenhouse design is that the greenhouse is safe to occupants. Public safety is of utmost importance. If the greenhouse were unsafe but could grow plants year-round, the greenhouse design would not be approved by the KGS Group, Health Canada and would not be used within the community. One of the objectives for the greenhouse design is to be able to sustain favorable conditions for produce production year-round in Manitoba. Therefore, the greenhouse must be able to operate in Manitoba's harsh temperatures and weather conditions. Furthermore, for the greenhouse to operate as intended, the greenhouse needs to be able to maintain conditions so that the greenhouse can be used to grow plants year-round. Lastly, the greenhouse must be interactive, and community based. Without buy-in from the community, the greenhouse will not be utilized even if the greenhouse is safe and can successfully grow produce. These needs were given an importance rating of 5, as they were the most important needs to consider for the greenhouse.

The greenhouse design must be economically viable to make the project of implementing geothermal greenhouses in northern Manitoba a worthwhile one. Additionally, as specified by the client, the usage of a geothermal heating system and use of renewable energy sources for electrical components are highly preferred. Therefore, the greenhouse design must have as little impact on the environment. These needs were given an importance rating of 4.

Needs that are important but dependent on other factors, are the greenhouse must be comfortable to work in and the overall size of the greenhouse. Measuring human comfort can be done partially through ergonomic analysis, however, comfort can also be subjective. The size of the greenhouse could easily be adjusted if building codes are met. These needs were given an importance rating of 3.

The team determined that the greenhouse should be in operable condition for at least 20 years which was selected based on the minimum life expectancy of geothermal systems. This need was given an importance rating of 2.

Specifications were created to set the expectations of the greenhouse design. The specifications are summarized in TABLE I.

TABLE I - GREENHOUSE METRICS AND TARGET SPECIFICATIONS

Metric #	**Need #**	**Metric**	**Units**	**Target Specs**
1	1,2,3,4	Internal greenhouse temperature	°C	20 ± 3
2	2,3,4	Storage temperature	°C	6.5-15
3	4	Light duration	hours	12-18
4	4	Daily light integral	mol/m2/day	12
5	1,4,9	Air exchanges	air exchanges/hour	2-180
6	4	Relative humidity	%	70-80
7	5	Inclusion of a community space	binary	pass
8	6	Installation costs of geothermal system	$	<100000
9		Integration of renewable energy sources	Binary	pass
10	8	Dimensions	m^2	<4800
11	10	Service life of materials and components	years	20

The final specifications are compared to the target specifications in Section 3. Conclusions and Recommendations.

1.4. Design Methodology

The team began with developing the needs and specifications for the greenhouse to satisfy the overall objective of providing the KGS Group a feasible geothermal greenhouse design to be implemented in northern communities to improve food security. Next, concepts were developed for each of the major areas of the greenhouse such as the location of the greenhouse, different facility layout options, materials, and power systems. Concepts were generated through internal brainstorming and gathering external sources such as suggestions from our client the KGS group and existing greenhouse designs. Concepts were screened based on criteria that were related to the needs of the greenhouse design. Weighted decision matrixes (WDM) were then used for concept selection to develop and move forward with the best design. Once concepts were selected, detailed design involved analytical and numerical analyses as well as sourcing components which met the overall needs and specifications of the greenhouse. Section 2. Detailed Design discusses the finalized geothermal greenhouse design proposed by Team 3 for the KGS Group.

2. Detailed Design

The detailed design includes a discussion on the different aspects of the greenhouse as well as their relationship to each other and any justification available relevant to their discussion. This section helps clarify what the greenhouse design is and why it was designed this way. Although some information has been relegated to the appendix the majority of the analysis, both numerical and analytical is presented in this section.

2.1. Overview

This section will provide a brief overview of the various components of the final design of the greenhouse in an attempt to provide a reasonable overview of the design. The location this design determined would be best for the greenhouse is Shamattawa Manitoba. This is a small community in northern Manitoba consisting of about 1000 people. It is accessible only by winter road and air travel and has some of the highest food costs in Manitoba. Despite the challenges present, such as the cold climate and the increased construction expense it was determined that Shamattawa is a reasonably ideal location for the greenhouse based on reasons such as the high food cost and population size. Within Shamattawa it is recommended that the greenhouse be built with a reasonable proximity to the rest of the of the community and the only local food store.

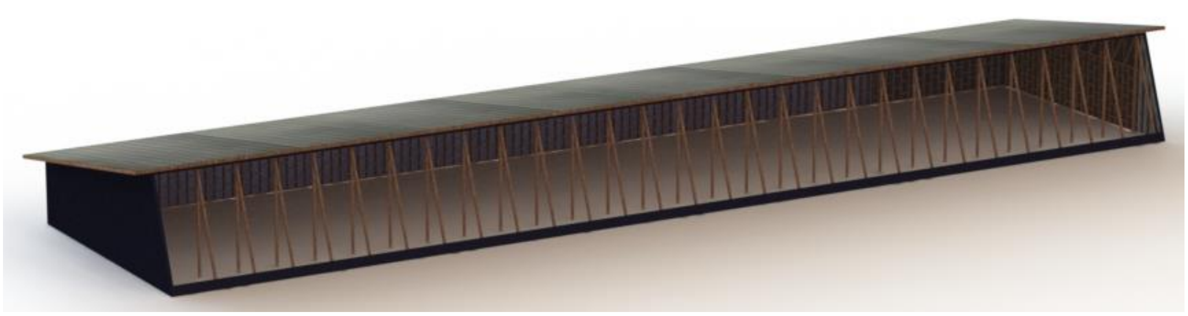

Figure 1 - Overview image of the greenhouse

The layout of the building is demonstrated in the above figure. The above figure demonstrates the general layout of the greenhouse including the clear southern face, sloped roof and flat east, west and northern walls. The greenhouse's most prominent feature is its clear southern face. The slope and size of this face is discussed in more detail in section 2.3 of this report however it has been adjusted in order to provide maximum solar energy to enter the building while attempting to minimize heat loss and building cost. Another Prominent feature is the sloped roof, which contains a change in height of 2 inches for every 12 inches of length. This feature was also adjusted, with consultation, to attempt to provide a reasonable sloped roof while also limiting the increase in building dimensions caused by an increased slope. The footprint also received some attention in an attempt to provide the most efficient floor plan as possible, it was determined that a layout of 50 meters east to west, and 10 meters north to south, with a height of 3 meters at the lowest point, would provide a reasonably optimal layout.

One of the most important parts of this design involved the selection of a geothermal heating system. Before this could be considered however some heat modeling and energy usage had to be considered. Heat modeling was completed via analytical analysis, both in this report via sample calculations and more fully within an excel spreadsheet. The final results of these heat loss calculations indicated a net loss in heat in December and January with a net gain in heat the remaining months of the year. This is only possible due to the large southern face and the use of a thermally insulating blanket which is rolled down in the evening and up in the morning to preserve heat while the sun is not providing solar energy.

With this heating in mind, it was determined that thermal balancing, the act of ensuring that the ground temperatures do not decrease beyond a reasonable degree, could be completed by taking heat from the internal air of the greenhouse during the months of excess heat. The heat pump selected, based on heating load requirements, reliability, and several other factors, is the WaterFurnace 7 Series 700A11. It was determined that two of these heat pumps should be put in place, increasing the heat flow capacity, and providing essential redundancy in the case that one of the heat pumps should fail.

Due to the isolated nature of the greenhouse location additional alternative power sources were considered, specifically the installation of wind and solar energy as a means to offset some of the energy requirements of the greenhouse.

2.2. Location

This section will discuss the chosen location of the geothermal greenhouse design. The various factors that influenced the final concept, and methods used for its construction, include human geography, environmental geography, and transportation of materials and equipment. These factors will be elaborated upon further, in relation to the final design concept.

2.2.1 Human Geography

Our greenhouse will be located within Shamattawa First Nation, a remote community that resides in north-eastern Manitoba on the Shamattawa 1 reserve [1]. This location was chosen, as it contains many factors pertaining to the needs of our client; large food subsidy costs, remotely located, and limited access to electricity [2] [3]. The community has a population size of approximately 1019 people (since 2016) [4], has only one grocery store [5], and relies on local diesel generation for power. The community is only accessible via the Shamattawa Airport, or by winter road [6]. Shamattawa First Nation has experienced issues of obesity and diabetes due to food insecurity issues within the community [7] [8] [9]. These factors would suggest that a geothermal greenhouse, capable of producing fresh, healthy crops, would be beneficial to the nutritional health, and energy efficiency of the community.

Shamattawa First Nation has seen many hardships over the years, including drug related crimes and violence [10], fluctuations in suicide rates [11], along with rises in cost of healthy food. Any introduction of construction projects must ensure the confidence of community members and carefully take into consideration the needs and desires of the community. This must be done to avoid any potential interference, which could cause delays or issues in completing the construction project.

IMAGE REDECTED

Figure 2- Satellite image of Shamattawa First Nation, Manitoba (Google Maps, 2021).

2.2.2 Environmental Geography

Shamattawa experiences large temperature fluctuations between, -40°C and +35°C, throughout the year, and sees mostly cloudy skies, limiting the effectiveness of solar panels [12]. Local wind speeds typically fall somewhere within the medium to high range, making it somewhat ideal for wind turbine energy. The region falls within the 50-90% permafrost level one, which makes construction projects rather challenging due to the thaw-freeze cycle of the active layer [13].

IMAGE REDECTED

Figure 3- Permafrost level map, indicating Shamattawa First Nation within the 50-90% zone

The community lies adjacent to the Gods and Echoing Rivers, contained within the Hudson Bay Lowland physiographical region. Being in proximity to a consistent water source [14] is ideal for the irrigation requirements of the greenhouse.

The municipal authorities of Shamattawa are the Keewatin Tribal Council, along with their current Chief Eric Redhead [15]. They comprise the governing body of the community and provide approval for any potential building projects (before a building permit application can be completed) [16]. Additionally, the geothermal greenhouse must abide by all relevant building codes set out by the Government of Manitoba [17].

The municipal authorities of Shamattawa are the Keewatin Tribal Council, along with their current Chief Eric Redhead [15]. They comprise the governing body of the community and provide approval for any potential building projects (before a building permit application can be completed) [16]. Additionally, the geothermal greenhouse must abide by all relevant building codes set out by the Government of Manitoba [17].

2.2.3 Transportation Routes

It is assumed that all structural, electrical, and mechanical components of the greenhouse, will be prefabricated and sourced within Winnipeg. These components would then be transported from Winnipeg, via Provincial Trunk Hwy 6 (north), Provincial Rd 391 (north-west), and Provincial Rd 280 (north-east) [18], to Gillam, then by the winter road route [19] to Shamattawa First Nation. Labor and equipment required to construct the greenhouse will be provided through contractors.

IMAGE REDECTED

Figure 4 - Provincial highway route, connecting Winnipeg to Gillam.

IMAGE REDECTED

Figure 5 - Winter Road, connecting Gillam to Shamattawa First Nation

2.2.4 Site Selection Considerations

The final construction site would be chosen at the discretion of the municipal governing authorities, the Keewatin Tribal Council and Chief Eric Redhead, and is out of the scope of this project. Features of the final site, that would be optimal for the geothermal greenhouse design, are listed below.

Ideal conditions of the final site would include:

- A large enough area to occupy the 500 m^2 building, with space for both the geothermal excavation and renewable energy components, that allows for optimal sun exposure (minimal sightline obstructions facing the southern horizon) for both the south-facing windows of the greenhouse, as well as the solar panels.
- Ground/soil compositions (obtained from preliminary drilling data), closely resembling those in section 2.5.3 in this report (sand and gravel, water content of 30% for completely saturated soil).

- Simultaneous proximity to both a consistent water source and road access, within a reasonable distance of the distribution center (the Northern Store).

2.3 Facility Layout

The layout of the building includes a description of its shape and dimensions as well as justifications for several features of the shape and dimensions.

2.3.1 Building Dimensions and Shape

The building shape is demonstrated in the figure INSERT FIGURE NAME which demonstrates the outline and arrangement of the walls and roof. Some of these angles have received specific attention to optimize the building to meet the specifications outlined earlier in this report.

2.3.1.1 Roof Height

This height is based off the requirements for vine plants, such as cucumbers and tomatoes to grow to a full height, as well as space for grow lights above the plants and space for insulation and roofing material. The selected height, 3m or 9.8 ft allows for 2 m of plant growth [20]and 1 m for lighting and insulation/roofing material. These values lack some optimization and would require some additional adjustment based on the type of plant and more specific data on optimal growing conditions for the selected plants.

2.3.1.2 Building footprint Width and length

The discussion on building footprint will be based off a footprint of 500 m^2. The width and length of the footprint are adjusted to provide as much solar energy as possible, maximizing the south facing side, while attempting to minimize heat loss and building costs from an extended surface area. The suggested dimensions are not an attempt to reach a fully optimized value, but provide an initial approximation based on an analytical evaluation. The footprint of the building is analyzed as if the building were built in a perfect rectangle, therefor surface area is considered by the following equation where W is width (north, south), L is length (east, west) and H is height, previously established as 3m.

$$Building\ Surface\ Area = 2L * W + 2L * H + 2W * H$$

The solar input, providing both solar energy for plant growth and thermal energy for HVAC considerations, is approximated by the surface area of the southern face, described by the following equation.

$$Southern\ Face = H * L$$

Based on these two equations the following graph demonstrates the ratio of solar input to thermal loss.

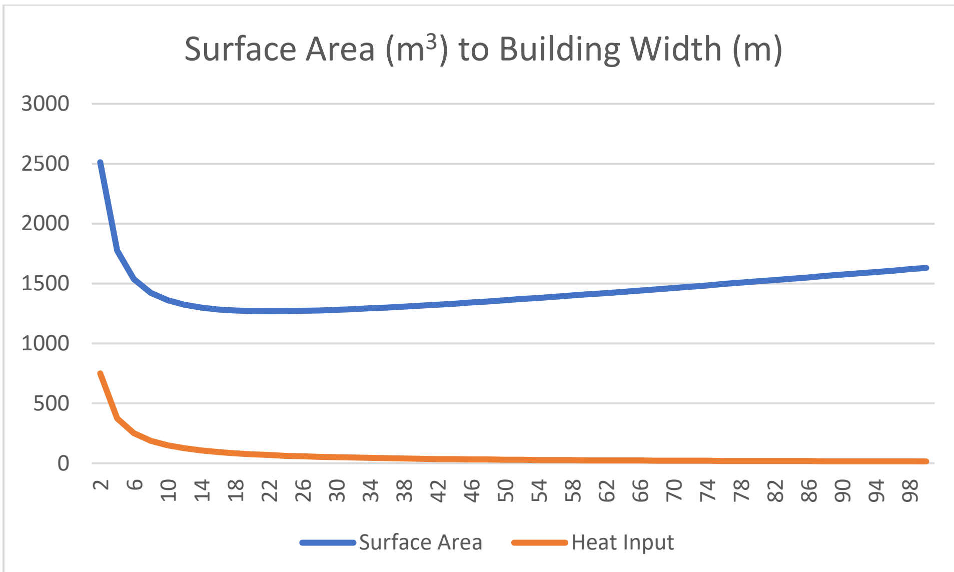

Figure 6 - This figure graphs both the full surface area and the southern facing area (heat input) on the y axis with the width of the greenhouse set as the x axis. This data allows for a visual indication of an optimal width.

The above graph demonstrates that although dramatic improvements in efficiency are achieved with an initial reduction in width, from 0 to ten, further reductions provide minimal improvements while they continue to significantly decrease thermal input. Based on a visual analysis of this graph, the values of 10m of width and a resultant 50 meters of length is selected for the building footprint. Further analysis, by calculating the actual building cost and heat loss to heat and light gain, would be a reasonable analysis for a future and more in-depth investigation.

2.3.1.3 Building Shape

The final building shape, demonstrated in figure 1 is the result of team discussion and analytical optimization. It was assumed that the building would have no variation in its cross section along its length, as demonstrated in figure 1. Based on this assumption optimization focused on improving this cross section in such a way as to minimize heat loss, maximize solar input and minimize building material cost. The initial layout of the cross section was a transparent material used for the southern face, a flat sloped roof and a vertical north facing wall. Several other designs were considered as described in prior reports. The optimization of this cross section focused on two aspects, the roof slope and the slope of the south facing wall.

The roof slope has several important factors, including its ability to shed water during rainfall or snow melt, the complexity and resulting cost to build the roof and supporting structure, the impact on wasted space within the greenhouse and the material cost in its construction. Several of these factors indicate that a minimally sloped roof, one which approaches horizontal, would be optimal, these factors include the supporting structure, minimized wasted space, material cost and complexity. The requirement for the roof to shed water however is only possible with a reasonable slope which is taken in this case to be at least 2/12 [21]. Based on these considerations the roof slope will be set at this minimal value of 2/12.

The roof slope has several important factors, including its ability to shed water during rainfall or snow melt, the complexity and resulting cost to build the roof and supporting structure, the impact on wasted space within the greenhouse and the material cost in its construction. Several of these factors indicate that a minimally sloped roof, one which approaches horizontal, would be optimal, these factors include the supporting structure, minimized wasted space, material cost and complexity. The requirement for the roof to shed water however is only possible with a reasonable slope which is taken in this case to be at least 2/12 [21]. Based on these considerations the roof slope will be set at this minimal value of 2/12.
The southern facing wall slope is considered based on the building complexity, the material required and the solar input. The solar input will take the $KWh/m^2/day$ which impacts the surface as the variable of consideration while the building complexity will assume to increase with increased slope and the material required will be taken as directly proportional to the surface area. By using the already determined minimum height of 3m, roof slope of 2/12, and building width of 10m several angles of the south face can be considered. The three options

analyzed here will be 80 degrees, 70 degrees and 60 degrees, with respect to horizontal. The amount of surface area can be calculated based on the other surfaces and provided angles. The solar input can be determined by multiplying the surface area with the amount of energy per square meter at that angle, determined in an online solar energy calculator [22]. These values are summarized in the table below.

Table ii - Summary of Window Angles

	Surface Area Glass m^2	Solar Input KWh/day	Complexity to Build
60 Degrees	234	2419	High
70 Degrees	233	2291	Med
80 Degrees	250	2094	Low

Further analysis could be performed to provide a more detailed optimization however the above table will be taken as sufficient for this initial analysis. Based on this table 70 degrees is selected as the slope of the south facing surface to minimize complexity, increase solar input and minimize the glass surface area. Based on these features the below cross section demonstrates the below figure demonstrates the cross section of the building, demonstrating the roof slope, glass wall (right) and some dimensions.

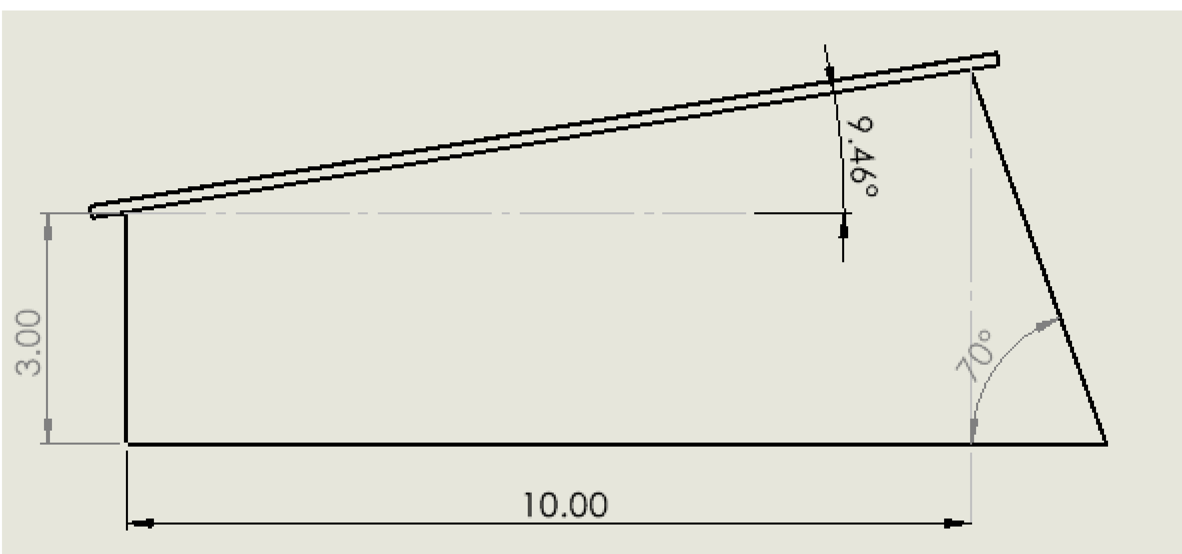

Figure 7 - Cross section of the greenhouse with basic dimensions and angles

Based on the above based features, the east, west, south, north, roof and floor have the following areas.

- North: 150 sq m
- South: 234 sq m
- East: 35 sq m

- West: 35 sq m
- Floor: 500 sq m
- Roof: 425 sq m

2.3.1.4 Entrance Area

The entrance area is designed to be a minimally insulated addition to the main building. The purpose of this add-on is to minimize air flow when the entrance to the greenhouse is used. The size of the entrance area should be large enough to prevent individuals from having both the entrance area door and the greenhouse door open at the same time while small enough to minimize the amount of cold air entering the greenhouse when its door is opened. For the purposes of this design the entrance area will be set at 2.5 m wide, 6 m long and 2.5 m tall . Based on the internal air volume of roughly 18 m^3 it will be assumed that about half of that air volume will be the amount of air exchanged by the greenhouse with the outside atmosphere every time the greenhouse door is opened, amounting to 10 m^3 of exchanged air at outside temperature per opening.

2.3.1.5 Community Space

The greenhouse is assumed to utilize 60 percent of the interior floor space for growing purposes. This is relevant in lighting costs and growing potential. This assumption, of 60 percent growing space, is not based on thorough analysis but attempts to account for both the requirements of a greenhouse in walking space and equipment storage as well as space for a portion of the greenhouse to be used as a community space. Many of the requirements for a community space within the greenhouse have not been analyzed within this report, such as the requirements for space separators or vapor barriers between growing and community space. Other, assumed more expensive aspects, of the community space have been considered, these include the plumbing costs for a kitchen and toilet and electrical costs for appliances and outlets. Some electrical use for this space has also been considered when analyzing the power requirements for the building.

With this in mind the community space aspect of the greenhouse should be considered as a preliminary suggestion, further analysis would be required to determine whether any of the requirements which have not been considered would add significant cost to the construction and would therefor make the community space a non-feasible option.

2.3.2 Layout Heat Losses

This section discusses the calculated amount of heat lost from the building during normal use. This is important when considering heating and power requirements, in subsequent sections of the report.

2.3.3.1 Background and assumptions

There are many assumptions required to facilitate hand calculations within the scope of the report which can provide helpful data on building heating requirements. Some of these assumptions are listed here while others are stated later within this section.

- The building is oriented cardinally, allowing this report to refer to each wall by the direction it faces.
- The layout, including surface areas and internal volumes, will match what is described in 2.3.1.
- Air density is taken as 100KPa both inside and outside of the greenhouse
- Values for R (gas constant) and the specific heat of air are taken from Fundamentals of Thermodynamics [23]

Values for R (gas constant) and the specific heat of air are taken from Fundamentals of Thermodynamics [23]

The walls, roof and floor sizes for this calculation will use the dimensions set out in 2.3.1 which describe the dimensions for this the greenhouse as 50 m long (East to West), 10 m wide (North to South) and 3 m tall at the lowest point of the roof. There will also be an entrance area, or equivalent air loss reduction method, to minimize air loss when the door to the greenhouse is opened. With this air loss feature it is assumed that 10 cubic meters of air will be exchanged each time the door is opened. Further, it will be assumed that the door is opened 72 times per day during daylight hours. The assumption of 10 cubic meters of air being exchanged is based on the size of the entrance area which approaches 10 cubic meters in volume and the assumption that most of the air in this area will be exchanged with the outside when the outer door is opened and that most of the air in this area will be exchanged with the inside when the inner door is opened. The assumption of 72 door openings per day is based off the estimate of one opening for every ten minutes with the building in use for 12 hours per day. These values should be reconsidered after community stakeholder consultation and input from industry specialists.

Air exchange can also occur through the envelope of the building. This is described by the infiltration rate and is dependent on building quality and materials used. As per Justin Albo P. Eng at CGM [24], a reasonable infiltration value to use for a greenhouse is 0.05 cfm/ft^2 (cfm describes cubic feet per minute). This translates to 10 973 cubic meters per day based on a footprint of 500 m^2. This value of air exchanged per day will be used in upcoming calculations to account for heat lost due to airflow through the envelope of the building.

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The heat loss calculations will use the R (insulation) values of various surfaces of the greenhouse for heat loss. These R values are drawn from building code requirements for the region of Manitoba which Shamattawa is in [25]. The R values required by code are included below, as are the equivalent RSI values (metric equivalent):

- Walls, R45/RSI 7.92
- Roof, R60/RSI 10.57
- Floor, R55/RSI 9.69

The heat loss data for the South wall is based off a fully glass triple-pane south wall face, other transparent materials were briefly considered in previously submitted reports [?]. While the sun is up it is assumed that these glass panes will be uncovered while, when the sun is down, it is assumed that an insulating blanket will be placed over the windows, providing an increased R value. The R values for these two setups are as follows:

- Windows Uncovered, R7.5/Rsi 1.32 [26]
- Windows Blanketed, R11.5/Rsi 2.03 [27]

The internal temperature of the greenhouse will aim to be at 21 degrees C with an acceptable range from 18 to 24 deg C. The internal temperature parameters is as per the initial standards, as provided by KGS. The weather conditions used are based off data acquired from MetroBlue [28]. These weather conditions are taken from the temperatures of 2020 and are only valuable for the initial analysis of system requirements. It is understood that further analysis and statistical modeling would be required to provide more helpful and accurate temperatures and temperature ranges to use for further analysis.

The internal temperature of the greenhouse will aim to be at 21 degrees C with an acceptable range from 18 to 24 deg C. The internal temperature parameters is as per the initial standards, as provided by KGS. The weather conditions used are based off data acquired from MetroBlue [28]. These weather conditions are taken from the temperatures of 2020 and are only valuable for the initial analysis of system requirements. It is understood that further analysis and statistical modeling would be required to provide more helpful and accurate temperatures and temperature ranges to use for further analysis.

The hours of sunlight used in these calculations are based of daylight hours available through an online solar calculator [22]. The solar radiative energy available at various angles is also available through the online solar calculator [22]. Because the heat flow calculations focus on providing a single value to be used for an entire month, the monthly average of the radiative energy will be used. The fraction of radiative heat which passes through the windows (the SHGC, solar heat gain coefficient) is taken to be 0.7 based on similar values for multi pane windows [29]. An additional modifying factor of 0.7 is used to account for cloudy weather and snow, this value is used in lieu of a modifying factor based on actual cloud cover data and should be understood as a significant simplification.

2.3.3.2 Equations

The following equations are used in the calculation sections

- Air Density(kg/m^3) = (Pressure)/((R value of air)*(Temperature in Kelvin)

- Volume of air exchanged= (air exchanged through envelope)+(air exchange through door)
    - Air through envelope= (Air through envelope per day)* (fraction of day considered)
    - Rate per second of air through envelope = air per day/(24*60*60)
    - Air exchanged by door= 720 m^3 for daytime calculations and 0 m^3 for night calculations
- Heat lost from air exchange=(specific heat of air)*(volume air exchanged or volumetric flow rate)*(air density)*(Temp difference)
- Heat loss through walls (Watts) =(temp. difference, deg C.)*(wall size, m^2)/(Insulation Value, RSI)
- Heat Loss through walls (KWH)= (Heat loss through walls in Watts) *(number of hours considered)/(1000)
- Solar Radiation Heat=(Window surface m^2)*(Ave. Daily thermal Input/m^2) *(SHGC) *(modifying factor)

2.3.3.3 Calculation 1: Peak Heat Transfer Rate Requirements

The first calculations done for heat loss are completed to measure the required heat rate transfer capacity of the heating system at an extended extreme nighttime low of -40 deg Celsius. Note that in the below calculations air exchanged through the door is excluded as this calculation because this calculation is for a nighttime heat flow and door openings are assumed to occur during the day.

- Temperature difference =internal Temperature – external temperature = 21-(-40)=61 deg C.
- Heat loss conducted through walls
    - Heat Loss Roof=(61)*(425)/(10.57)=2452 W
    - Heat Loss Floor=(61)*(50*10)/(9.69)=3147 W
    - Heat Loss North Wall=(61)*(50*3)/7.92=1155 W

- Heat Loss East Wall=(61)*(34.95)/7.92=269 W
  - Heat Loss South (glass) Wall=(61)*(238.35)/2.03=7162 W
  - Heat Loss West Wall=(61)*(34.95)/7.92=269 W
  - Sum Heat Loss conducted through surfaces=14 434 Watts=14.4 KW
- Heat lost by Airflow = (volume air exchanged)*(Temperature Difference)*(Specific heat of air)
  - Air density =100/(0.287*(273.15-40.0))=1.4944 Kg/m^3
  - Rate per second of air through envelope = 10973/(24*60*60)=0.127m^3/s
  - Heat lost from air exchange=1.004*0.1270*1.4944*61=11.62KW

This heating requirement can provide an initial estimation for the maximum heating rate that the greenhouse heating system would need to be able to provide. Based on these values it is suggested that the heating system be able to provide equal to or more than 26.02 KW.

2.3.3.4 Calculation 2: Annual Heating load

Because geothermal systems are being considered for this system it is important to know not only the peak heating load but also the sum heat required during a year. This calculation could include significant complications depending on the precision to which it is completed. For this report a simplified calculation will be done to provide some general estimates. The heat exchange will be based on an analysis which separates each day into daylight and night. During daylight the greenhouse will be analyzed with the windows uncovered, with the input of solar radiation through the window, with regular door openings and using the average monthly high temperature. During the night it will be analyzed with the windows insulated with a thermal blanket, without solar radiation input, without any door openings occurring and using the monthly average low temperature. The number of hours of the day separated into daylight and night are based on the average number of hours of sunlight as described by the online daylight calculator [22].

Because geothermal systems are being considered for this system it is important to know not only the peak heating load but also the sum heat required during a year. This calculation could include significant complications depending on the precision to which it is

completed. For this report a simplified calculation will be done to provide some general estimates. The heat exchange will be based on an analysis which separates each day into daylight and night. During daylight the greenhouse will be analyzed with the windows uncovered, with the input of solar radiation through the window, with regular door openings and using the average monthly high temperature. During the night it will be analyzed with the windows insulated with a thermal blanket, without solar radiation input, without any door openings occurring and using the monthly average low temperature. The number of hours of the day separated into daylight and night are based on the average number of hours of sunlight as described by the online daylight calculator [22].

January, with the coldest average temperatures, will be used as an example for these calculations.

- January Night:
    - Temperature difference= 21 –(-26.6)=47.6 deg C.
    - Heat loss through surfaces = **187.42 KWh**
        - Heat Loss Roof=(48.6)*(425)/(10.57)=1954 W
        - Heat Loss Floor=(48.6)*(50*10)/(9.6)=2531 W
        - Heat Loss North Wall=(48.6)*(50*3)/7.92=920 W
        - Heat Loss East Wall=(48.6)*(34.95)/7.92=214 W
        - Heat Loss South Window Wall=(48.6)*(238.35)/2.03=5706 W
        - Heat Loss West Wall=(48.6)*(34.95)/7.92=214 W
        - Sum of heat loss through surfaces (Watts) =11541 Watts
        - Sum of heat loss through surfaces (KWh)=(11541)*(16.24)/1000=187.42 KWh
    - Heat loss through air exchange **= 139 KWh**
        - Air Density =100/(0.287*(273.15-26.6))=1.413 Kg/m^3
        - Air through envelope=(10973)*(16.24/24)=7425 m^3
        - Heat lost from air exchange=1.004*7425*1.413*47.6=501394 KJ=139 KWh
- January Day,

- Temperature difference= 21 –(-19.3)=40.3 deg C.
- Heat loss through surfaces = **96.19 KWh** (see subpoints)
  - Heat Loss Roof=(41.3)*(425)/(10.57)=1661 W
  - Heat Loss Floor=(41.3)*(50*10)/(9.69)=2131 W
  - Heat Loss North Wall=(41.3)*(50*3)/7.92=782 W
  - Heat Loss East Wall=(41.3)*(34.95)/7.92=182 W
  - Heat Loss South Window Wall=(41.3)*(238.35)/1.32=7457 W
  - Heat Loss West Wall=(41.3)*(34.95)/7.92=182 W
  - Sum of heat loss through surfaces (Watts) =12396 Watts
  - Sum of heat loss through surfaces (KWh)=(12396)*(7.76)/1000=**96.19 KWh**
- Heat loss through air exchange = **67.48 KWh**
  - Air density =100/(0.287*(273.15-19.3))=1.373 Kg/m^3
  - Volume of air exchanged by door= 10*72=720 m^3
  - Air through envelope=(10973)*(7.76/24)=3548 m^3
  - Volume of air exchanged = 3548+720=4268 m^3
  - Heat lost door opening=1.004*4268*1.3726*41.3=242914 KJ=67.48 KWh
- Solar Radiative Heat Received=238.35*2.59*0.7*0.7=**302.49 KWh**

Based on these calculations the January heat change during the night is equal to a net loss of 326.42 KWh while the January heat change during the day is equal to a net gain of 138.82 KWh. These calculations are repeated for each month and the results included below. The full calculations, completed via excel spreadsheet, are available as a separate document, provided with this report.

Table iii - Summary of Heat Losses

DAILY TOTALS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heat Loss During Day (KWh)	-144.202	-334.1773	-532.93	-844.15	-976.29	-1067.2	-1092.5	-1014	-823.15	-540.96	-262.36	-103.47
Heat Loss During Night (KWh)	424.4571	292.5587	153.94	125.12	75.838	45.557	33.673	45.08	79.326	132.62	224.91	325.57
Heat Loss Day+Night (KWh)	280.2552	-41.61869	-378.98	-719.03	-900.45	-1021.6	-1058.8	-968.93	-743.82	-408.34	-37.452	222.1

2.4 Materials

With the layout of the greenhouse established, the next step will be to determine the materials and component that would be required to implement the greenhouse. This section will look into the key areas of the greenhouse and will provide a cost estimate as well as an estimate for the time of installation.

2.4.1 Excavation and Foundation

The first step of building the greenhouse that will need to be considered is the excavation. Before the foundation can be built, the surrounding soil must be removed. Based on the dimension given for it was estimated that the volume of soil that needs to be removed will be 480 m^3. This estimate was based on the dimensions of the foundation that will be install. An assumption was made that the excavator will be using a 1-yard bucket (1 cubic yard) and a removal rate of 0.5 buckets per minute [30]. That results in 30 cubic yards being removed per hour or 23 cubic meters. With a total of 480 m^3 of soil needing to be removed, a total time of 21 hours is required to remove the necessary soil.

The time allotted to the excavation for this project will be 5 days. Assuming an 8-hour workday, it will a little over 3 days to finish the excavation. Extra will be allotted to account for any minor issues such as weather or issues with equipment.

With excavation finished, the next step in building the greenhouse will be constructing the foundation. For this greenhouse, a perimeter concrete beam of dimension (250x900mm) with a footing of (300x900mm). This can be seen below in Figure 8 - Foundation Drawing. There will be both vertical and horizontal foamboard insulation. Once the concrete is poured, it takes about 25-28 days for the concrete to cure to its full strength [31]. After about a week, the concrete should be strong enough to walk on. Once the foundation is poured and complete, backfilling can be done. This is the process of filling in the remaining space between the foundation and the excavated area. It is assumed that due to remote location, the soil removed from the excavating will be used for the backfill.

Figure 8 - Foundation Drawing [32]

The total cost of the excavation, backfill and insulation was estimated to be $125,000.00 CAD [32] . The cost of the concrete and forming was estimated to be $250,000.00 CAD.

2.4.2 Framing and Siding

With the foundation completed, the framing can begin. This greenhouse will use a steel frame with an off-center distance 6250mm. For the siding and the roof, insulated metal panels (IMP) will be used. IMPs are prebuilt metal panels that have a foam core [33]. IMPs have an interlocking grove that allows 2 pieces to lock together and once in place, they are secured by concealed clips and self-tapping Tek-style fasteners [34]. One major benefit to using IMP over traditional wood framing is the ease of installation. Since the panels are prebuilt, this will require less on-site labor and will reduce time required to erect the building. Another benefit to IMP are their high insulating properties and strong moisture barrier. A R-Value of 27 is required for the walls and an R-Value of 41 is required for the roof [32]. For the walls, 4in panels will be used and will have an R-Value of 32.5. For the roof, 5in panels will be used and will have an R-Value of 41.5.

IMAGE REDECTED

Figure 9- IMP Interlocking Grove

In industrial setting, a 4-man crew can erect 5000 ft^2 of IMP per 8 hours [34]. With an approximately 27000 ft^2 of required IMP, with 8-hour shift, it will take approximately 5.5 days to complete the installation of the siding and the roof.

The total cost for the steel framing which includes material and labor is estimated to be $350,000.00 CAD [32]. The cost for IMP and the installation cost is estimated to be $300,000.00.

2.4.3 Thermal Blanket for South windows

One of the heat saving features utilized in the greenhouse is the thermal blanket which rolls onto the south facing glass at sunset and is removed at sunrise. This device decreases the heat and radiative energy lost through the south facing window at night while allowing the daytime thermal input to enter without interruption. Because of the exposed layout of this blanket, it would need to have some waterproofing on the exterior facing side. It is also expected to have a reflective surface on the interior facing side and to provide an R value of 4 (RSI 0.7). Additional information from vendors would be necessary to optimize the blanket selection however a rough estimate, to establish average cost, and ensure that the described blanket could likely be acquired will suffice for this report.
Alibaba.com provides several options for thermal blankets, ranging from 3-7 USD/m^2 [20]. These include a felt material with an aluminum foil covering on one side at a weight of 1.25 kg/m^2. Other websites provide a lighter but double foil layered blanket for 3USD/m^2 [21]. Despite lack of R values for the described blankets based on these items, and by working with supplies it is reasonably certain that a thermal blanket, with the described features, could be obtained for a range of 3-7 USD/m^2 because of the exposed outer face the upper limit, 7 USD will be used for this evaluation.

The motor and rolling system design are not explored within this report however the ClearPath DX100 Motor, with an average power of 3 hp [22], will be used for cost analysis. It will be assumed that six of these motors will be used, one on either end and one at every 10 meter interval. The average unit cost for this motor will be used, which is roughly 1000 USD.

The accessories, racks or other equipment necessary for setup will be estimated to double the motor cost, leading to a final price for the blanket system of (motor cost)*2+(sq ft of windows)*(blanket cost)=5000*2+7*238=11 666 USD, plus shipping and taxes.

2.4.4 HVAC

The greenhouse will require some type of HVAC system to control the indoor conditions. Due to focus of this project being a feasibility study, the full design of an HVAC system will not be in the scope of this project. However, the team has highlighted potential components and aspect that the greenhouse might require. These components and an estimated cost are as follows [35]:

- Tempeff high efficiency Heat Recovery Ventilator = $80,000.00 installed including ductwork
- HVAC control system (DDC) = $45,000.00
- Ductwork, grilles, vents, and other general HVAC equipment = $20,000.00
- Air balancing = $15,000.00
- Travel and accommodations for workers = $7,000.00

It was determined that it would take just under two weeks install all the necessary HVAC components [36].

2.4.5 General Electrical and LED's

It should also be noted that, due to the preliminary nature of the report it is possible that with further expertise and research more optimal grow lights could be selected than those sourced here, this could impact both power requirements and the purchasing cost. Initial lighting cost is estimated at 1$/watt for LED lights. This is based off of the Covert LED-X Full Spectrum LED light at 100 Watts and 99.95$ [16] with several supporting examples such as the HLG Saber, 134$/120 Watts[11], the T5 36 Watt Full Spectrum Light, 70$/62Watts [12], or the Monios-L T8 LED Grow Light, 90$/144Watts[13]. Further, the full indoor space will not be considered for lighting requirements. The amount of indoor space used for growing will vary depending on the priorities of stakeholders as well as the physical requirements for food production. Because obtaining actual values for these factors is beyond the scope of this report, requiring stakeholder consultation and additional investigation, this report will assume a growing space consisting of 60% of the indoor area or 300 m^2 out of the 500 m^2 of indoor space.

Lighting requirements for indoor plants vary depending on the amount of natural light available, the plant selected to be grown and the desired efficiency of growth. Based on a report from e-gro.org [17] the minimum DLI (mol/m^2/day) for tomatoes is 20, peppers 20, cucumbers 15, head lettuce is 12 and bedding plants are 8. Because the specific vegetable layout is not specified in this report an average of these values will be used across the greenhouse for lighting calculations, this provides a value of 15 DLI. Because of the full southern facing window, it will be assumed that some portion of the lighting requirement will be fulfilled by the incoming sunlight. The exact amount is beyond the scope of this report so it will be assumed that one half of the lighting requirements will be fulfilled by the incoming sunlight. Based on this the required light input from LED sources is 7.5 DLI. Because some plants require periods of darkness to provide stable growth, such as tomatoes requiring 4-6 hours of darkness [17], it will be assumed that the lights run for ¾ of the day, or 18 hours, with ¼, or 6 hours, of unuse.

Using the lighting requirement of 7.5 DLI, the Covert LED-X Full Spectrum LED light [16] and a use factor of ¾ the grow lighting power and cost requirements can be calculated. This light provides 240µmol/s which translates to 15.552 mol/day based on a conversion factor of 60 (sec/min) *60(min/hour) *18(hours/day)/1 000 000 (µmol/mol). With a lighting requirement of 7.5 mol/m^2/day and light output of 15.552 mol/day each light fixture would provide enough coverage for 2.07 m^2. With a growing space of 300 m^2 145 of the specified lights would be required (rounded up from 144.93). With each light having a purchase price of 99.95 (excluding shipping and taxes) and a wattage of 100 Watts the full cost would be 14 492.75$ and the full wattage requirement would be 14 500 W which, when used for the described period, would translate to 261 KWh per day.

With the lighting for the growing area the next element to determine is the general electrical work. Due to the scope of this project, a detailed design of this electrical work will not be included. The following aspects and components for the general electrical are as follows [35]:

- Lighting for common area = $10,000.00
- Fire alarms and exit signs = $25,000.00
- Power supply to building = $40,000.00
- Power supply to mechanical equipment = $25,000.00
- Miscellaneous electric power = $15,000.00
- Travel and accommodations for workers = $20,000.00

It was determined that it would take approximately 6 weeks to install all the necessary electrical components. It is assumed that a 4-man crew would be flown in to complete the necessary work [37].

2.4.6 Solar Panels and Wind Turbines

Shamattawa is a community that is reliant on one of four diesel generating stations in Manitoba for their electrical needs. Due to high service rates for electricity from diesel generating stations, the KGS Group requested that the greenhouse would be primarily powered using solar panels and wind turbines.

The number of solar panels and wind turbines to provide enough power for normal operations of the greenhouse was based on the expected daily electrical loads of the greenhouse. From Section 2.4.5, we see that the grow lights use 261 kWh of energy daily. Based on performance charts of the WaterFurnace 7 Series 700A11 Heat Pumps, the maximum power requirement for each of the pumps is 5.01 kW [38]. Therefore, if both heat pumps were operating at full load for 24 h, then the energy requirement for the heat pumps would be 240.48 kWh. The pump for the ground loop requires approximately 3 kWh per pump [39]. An average 50-gallon electric water heater operates for three hours a day and requires 16.5 kWh of energy [40]. The average home in Canada uses 11135 kWh of electricity per year and 14% of electrical energy usage in Canadian homes is used for appliances [41], [42]. The electrical energy requirements for the community space in the greenhouse was assumed to be the same as the electrical energy usage for appliances in the average Canadian household, resulting in 4.3 kWh per day. The total energy requirement per day of the greenhouse was estimated to be approximately 529 kWh by summing the previously discussed energy requirements of the major devices within the greenhouse. Note that the auxiliary heaters would cause the daily electrical energy requirement to increase. However, under normal operation, the auxiliary heaters should not be in use and was therefore excluded in the average daily electrical energy requirement of the greenhouse.

The space required for the solar panels and wind turbines were based on each power source supplying half of the average daily electrical energy requirement. Each source is to supply half the average daily electrical energy requirement to reduce the reliance on one system if solar or wind energy is not available.

Sizing the solar panel system was based on half of the average daily electrical energy requirement, energy efficiency of the solar panels and average sunlight hours per day available in Shamattawa. A typical energy efficiency for solar panels is 15% [43]. Taking the average of the sunlight hours from the heat load calculations over the course of a year resulted in 12 hours of sunlight on average per day. The power requirement of the solar system was calculated to be 25.4 kW. One popular solar panel option available in Canada is the Hanwha Solar Canada HSC-250-60P model [44]. One HSC-250-60P panel can produce 250 W of power. Therefore, to meet half of the power demand of the greenhouse, 102 panels were required. The dimensions of each HSC-250-60P panel are 1652.5 mm x 1002 mm x 50 mm. The space required for 102 panels would be approximately 169 m^2 based on the length and width of each panel. Although the solar panels would not be oriented horizontally, 169 m^2 was deemed acceptable for an estimate as there needs to space between panels to maximize the solar energy absorbed by the panels. The average cost of solar panels per watt in Manitoba is $2.90 [45]. As a result, the cost for the 102 panels works out to be approximately $74000. The solar panels are to be installed on the ground for ease of installation and service (ie. clearing the panels of snow in the winter).

Assuming wind energy is available for 24 hours a day, the power supplied by the wind turbine system must be 11 kW to satisfy the greenhouse power requirements. The Anorra 48 Home Wind Turbine by BORRUM ENERGY SOLUTIONS is recommended to supply power for the greenhouse as the design is made to withstand the harsh temperatures and climate within Canada [46]. The Anorra 48 has a rated power of 1.1 kW at 45 km/h. Therefore, 11 wind turbines are required to supply 11 kW of power. The size requirement for 11 Anorra 48 wind turbines is 465 m^2. The cost per Anorra 48 is $6491 for one wind turbine and $71400 for 11 wind turbines.

As wind and solar energy sources cannot provide electrical energy on demand, the wind and solar systems will be tied to a battery storage system as well as have electricity from the diesel generating station as a backup. A possible energy storage solution would be to use three TROES TI-50-220 lithium-ion batteries which together can store 585 kWh worth of energy, more than the energy required for one day of normal operation of the greenhouse. An inverter would need to be sourced to convert the DC voltage from the batteries to AC voltage to be used by common devices such as the appliances within the community space and the heat pumps. Batteries for renewable energy systems last up to 20 years and costs roughly $126 per kWh of stored energy, resulting in a total of $73710 for the batteries for the greenhouse [47].

A summary of the parameters of the solar and wind systems to be used to power most of the electrical components within the geothermal greenhouse are shown in TABLE IV.

TABLE IV - SUMMARY OF RENEWABLE ENERGY SYSTEMS IMPLEMENTED WITH THE GEOTHERMAL GREENHOUSE

Parameter	Value
Average Daily Electrical Energy	529 kWh
Solar Panel Selection	Hanwha Solar Canada HSC-250-60P
Number of Solar Panels	102
Solar Panel Field Sizing	169 m^2
Wind Turbine Selection	Anorra 48
Number of Wind Turbines	10
Wind Turbine Field Sizing	465 m^2
Energy Storage	Three TROES 50kW,220kWh Indoor Cabinets
Total Cost of Installation of Renewable Energy Sources	$219110

2.4.7 General Plumbing and Irrigation

The last aspect of building the greenhouse will be the plumbing and irrigation system. The greenhouse will require an irrigation system for the plants as well as standard plumbing that would be required. Similar to the electrical and HVAC components, a detailed design for the plumbing is considered to be out of scope for this project. However, the team has highlighted potential components and aspect that the greenhouse might require. These components and a cost estimate are as follows:

- This includes water filters replaced every 3-5 years: $1,500.00 without shipping and taxes [23]
- Water and Sewer = $20,000.00
- Basic Plumbing = $40,000.00, including kitchen and bathroom: 15 000 USD equipment and installation [24] based on plumbing for a 1 bath 1 kitchen and cost increase of two based on location
- Drip system connectors, line, and installation: $20,000.00, based on the costs of various components described at an online irrigation store [25]
- Water storage tank $3,800.00, doubled from the listed purchase cost of $1,900.00 based on shipping and taxes.
- Travel and accommodations for workers = $20,000.00

It was determined that it would take approximately 6 weeks to install all the necessary plumbing and irrigation components. It is assumed that a 4-man crew would be flown in to complete the necessary work [48].

2.5 Geothermal System Design

The greenhouse design required external heat and electrical sources to maintain the internal temperature of 21°C ± 3°C to sustain plant growth year-round. Due to Manitoba's harsh weather conditions and outdoor temperatures, the greenhouse required an efficient method of heating and cooling for both human comfort and plant growth.

2.5.1 Geothermal Configuration

The greenhouse was designed to be heated passively and store excess generated heat in the ground. With the use of a heat pump, the greenhouse could be heated and cooled assuming the geothermal system is thermally balanced. A geothermal system is balanced when the amount of thermal energy being dumped into the ground is equal to the amount of thermal energy extracted from the ground into the building over the lifetime of the geothermal system. A vertical closed loop, horizontal closed loop, pond/lake closed loop, and open loop geothermal configuration were considered for the greenhouse. A weighted decision matrix was used to compare the configuration types in respect to parameters such as installation costs, service requirements and weather considerations to name a few. Since there was no strict requirement for the maximum space of the greenhouse, the horizontal closed loop configuration scored the highest because of the relative ease of installation and minimal maintenance. Therefore, a horizontal closed loop system was designated as the geothermal configuration for the greenhouse.

2.5.2 Heat Pump Selection

A suitable heat pump was selected based on the maximum heating loads of the greenhouse. Note that the maximum heating load was used as the load to base the heat pump selection as in Manitoba, the heating load in the winter far exceeds the cooling load on a summer day. Heat losses due to conduction out of the walls of the greenhouse and due to convection from forced air exchanges and leakage were considered in the calculations. Heat in the form of radiation absorbed by the greenhouse through the windows was also considered. A winter temperature of -40°C was assumed as the coldest temperature that would be experienced in Shamattawa. Based on the heat load calculation on the coldest night of the year, 26.042 kW of thermal energy would be required to heat the greenhouse to 21°C. Details of the heat load calculations can be found in Appendix A. Converting the 26.042 kW to BTU/hr, results in 88899.95 BTU/hr.

According to CSA standards, a geothermal heat pump system must be able to supply 70% to 105% of the heating load of the building [49]. Rob Sinclair, Engineering Specialist Advisor with the KGS Group with expertise in geothermal systems, recommended that multiple smaller heat pumps be utilized within our geothermal greenhouse design to limit the impact on the greenhouse in the event of a heat pump failure [50]. The selection of heat pumps began with looking at a spreadsheet of approved and most efficient geothermal heat pumps available in Canada, which was provided by ENERGY STAR [51]. The heat pump options were limited to closed loop air-to-water systems. However, there were over 300 heat pumps remaining to choose from. The list was then ordered based on the greatest sum of coefficient of performance (COP) and energy efficiency ratio (EER). The COP refers to how efficient the heat pump is converting electrical energy into heat, whereas the EER refers to how efficient the heat pump is at cooling the building. With a COP of 4.5 and EER of 36.4 as well as control systems for humidity and air flow, two WaterFurnace 7 Series 700A11 with Aurora Control heat pumps with a capacity of 46000 BTU/h were selected.

If the heat pumps cannot meet the building heat loads on a given day, auxiliary electric heaters will be connected to the same control system as the heat pumps to maintain the internal greenhouse temperature between 21°C ± 3°C. Two auxiliary heaters supplied by WaterFurnace with a model number of EAL(H)15 that are compatible with the Aurora Control system was selected for the greenhouse. The auxiliary heaters can provide up to 49100 BTU/h each, which is like the capacity of each heat pump.

2.5.3 Geothermal Field Details

When the heat pumps were selected, the next step was to determine the details of the geothermal field, such as the length of pipe required to maintain a storage ground temperature between 6.5°C to 15°C, piping depth, internal diameter of the piping and selection of the heat transfer fluid within the piping. Geothermal field refers to the entire space that the geothermal system encompasses.

The length of the piping placed underground was determined based on the minimum length required for the heat transfer rate between the ground and the greenhouse on the assumed coldest day of the year of -40°C and the maximum allowable length that could be used based on the minimum flow rate of the heat transfer fluid in the ground loop for the heat pump.

The Ingersoll method for selecting a minimum piping length for the ground loop was used [52]. The Ingersoll method relates the rate of heat transfer (q) between the ground and the building, temperature difference between the ground and the fluid within the pipes (t_g-t_w), and the thermal resistance of the ground (R) with the length of the piping required for the ground loop (L). One limitation of the Ingersoll method is that only short-term variances are considered, ie. the length of the piping is determined based on a single day when the heating load is assumed to be the greatest. Another limitation with the Ingersoll method is that the method is typically used for vertical closed loop systems. Our geothermal greenhouse features a horizontal closed loop system. However, the reason why the Ingersoll method is typically only used for vertical closed loop systems, is that horizontal closed loop systems are usually heavily influenced by the weather as the piping in horizontal closed loop systems are typically 1.2 to 1.8 m deep which is relatively close to the surface [52]. Therefore, for the method to be accurate, a depth where the piping will be less influenced by the weather must be selected. After consulting with Rob Sinclair, piping depths of 20 ft and 25 ft were selected and the piping should not be severely impacted by the weather. The heat transfer equation used in the Ingersoll method is shown below [50].

$$q = \frac{L(t_g - t_w)}{R}$$

Taking the maximum heat load requirement of 24.064 kW on the coldest day of the year, with a ground temperature of 15°C, fluid temperature of -1.1°C and soil thermal resistivity of 0.796 (m °C)/W, resulted in a total pipe length for the two heat pumps of 1288.14 m. The ground temperature was taken as 15°C based on the upper bound of the ground temperature specification for the greenhouse, as the intent of using the Ingersoll method was to find the minimum length required. Selecting the lower bound for the ground temperature specification of 6.5°C would result in a greater pipe length and would not provide the minimum length. The fluid temperature was assumed to be -1.1°C based on the minimum temperature that the heat pump would operate for the heating mode [38]. The thermal resistivity of the soil was based on geological reports from Shamattawa which states that sand and gravel is expected 1.8-8.2 m below ground level and that the water content in sandy soils is typically 30% for completely saturated soil [53], [54], [55].

The maximum piping length was determined based on the maximum allowable head losses and required minimum flow rate. An Access Engineering spreadsheet by McGraw-Hill Global Education Holdings, LLC. was used to find the maximum allowable piping length based on the calculation of the major and minor head losses as well as the minimum required flow rate for the heat pump [56]. The details of the analysis are shown in Appendix A. Based on the recommended flow centers by WaterFurnace to use with the WaterFurnace 7 Series 700A11 heat pumps, two GRUNDFOS UPS40-240, 230 V pumps in series were selected. The two GRUNDFOS UPS40-240, 230 V pumps in series allow for up to 115 ft of head losses to maintain the minimum heat pump flow rate of 5 gpm based on the performance pump curve as shown in Figure 10 [38], [39].

IMAGE REDECTED

Figure 10 - Performance pump curve for two GRUNDFOS UPS40-240, 230 V pumps [39].

The pipe material was selected to be HDPE based on consultation with Rob Sinclair [50]. Therefore, the pipe surface roughness was assumed to be 0.00007 ft [57]. The heat transfer fluid was selected to be a mixture of 20 wt% propylene glycol and 80 wt% water. Propylene glycol was selected as the heat transfer fluid freezing point is lowered to reduce the chances of freezing fluid which would result in burst pipes. Propylene glycol was selected as the antifreeze medium compared to other options such as ethanol or ethylene glycol, as propylene glycol is non-toxic and reduces the harm to the environment in the event a leak or spill were to occur. A mixture containing 20 wt% propylene glycol is within the acceptable range of antifreeze weight percentage for the heat pump [38]. DOWFROST™ GEO 20 was selected as the specific antifreeze solution to be used within the ground loop, as it is ready to use which minimizes down installation time [58]. DOWFROST™ GEO 20 has a freezing temperature of -7.5°C which is well below the expected soil temperature in Shamattawa with depths of 20 ft and 25 ft, especially with thermal energy being dispersed into the ground following the completion of the construction of the greenhouse. Additionally, DOWFROST™ GEO 20 offers corrosion resistance.

The minor head loss coefficients were determined based on a rough estimate on the type and quantity of fittings in the ground loop design. Two couplings, eighteen 180° bends, four 90° elbow bends with a long radius, eighteen tees and two unions were accounted for which resulted in a sum of minor head loss coefficients of 37.96. To account for any additional fittings or valves, an additional value of 300 was added to the minor head loss coefficients, for a total of 337.96.

The pipe diameters and overall maximum length of the ground loops were adjusted until a standard pipe diameter was achieved, the overall length of the ground loops based on the head loss calculation exceeded the minimum length value established from the Ingersoll method and resulted in a flow rate that exceeded the minimum working flow rate for the heat pump of 5 gpm. The pipe internal diameter was determined to be 1.25 in and overall maximum length of the ground loops was 10400 ft (3169.92 m) which resulted in a fluid flow rate of 5.02 gpm. Recall that the minimum ground loop length was 1288.14 m total between the two loops from the Ingersoll method. However, this minimum length was obtained assuming a ground temperature of 15°C was achieved. From the Ingersoll method, the length of the piping is inversely proportional with the difference between the ground temperature and the fluid temperature. Therefore, the larger the pipe length results in a lower ground temperature. The final length of piping determined from the Ingersoll method, pump requirements and COMSOL simulations resulted in 2700 m of piping to ensure that enough heat can be supplied to the greenhouse year-round. Note that 2000 m was used in the COMSOL simulations as the length of the horizontally oriented pipes in the ground. However, due to the depths of the piping, the piping must be installed through horizontal boring which requires an entrance angle of 8° to 16° which increases the length of piping and is accounted for in the extra 700 m [59]. The length of two headers was also included in the extra 700 m. The 2700 m piping was divided into 10 loops, 5 loops with a maximum depth of 20 ft and 5 loops with a maximum depth of 25 ft.

Simplified diagrams of a side view and top view of the geothermal field are shown in Figure 11 and Figure 12. The red lines in Figure 12 represent hot fluid from the greenhouse whereas the blue lines represent cold fluid going towards the ground.

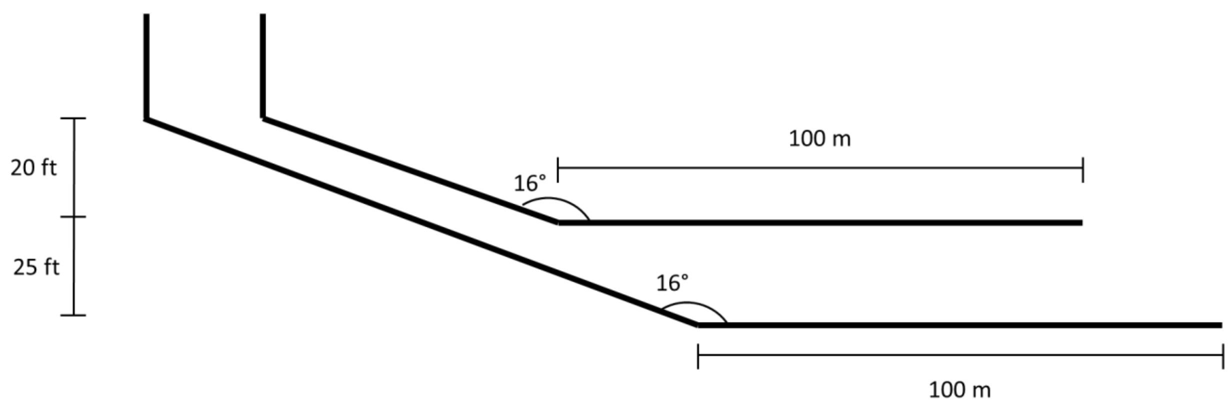

Figure 11 - Side view of the geothermal field.

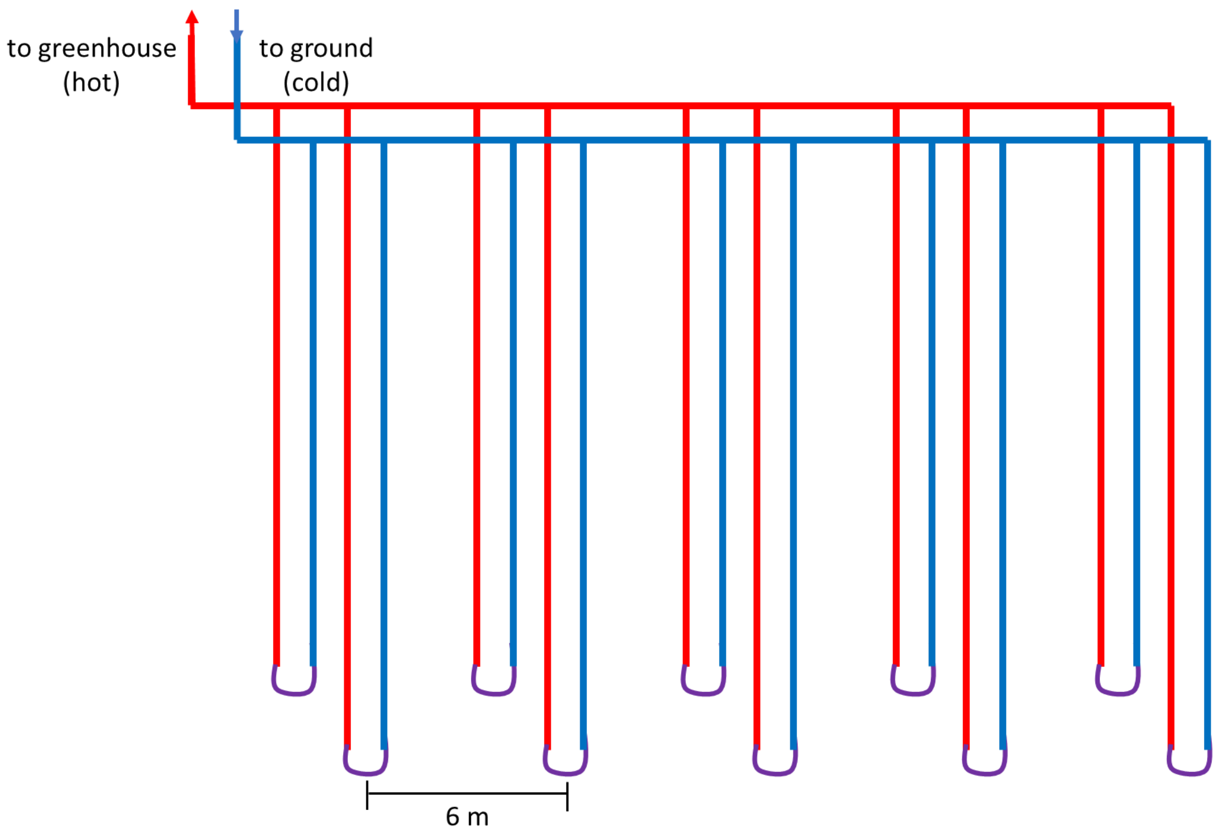

Figure 12 - Top view of the geothermal field in heating mode.

The total cost of the geothermal system was $71300 which was established with the help from Ray Bodnar, Senior Mechanical Engineer with the KGS Group [35]. More details about the cost of the geothermal system can be found in Section 2.8. Cost Analysis.

2.5.4 Control Systems

The WaterFurnace 7 Series 700A11 heat pump comes with an Aurora Variable Speed Control. The Aurora Variable Speed Control can control the temperature within the greenhouse by adjusting the flow rate of the fluid in the ground loop, as the flow rate is directly correlated to how much heat transfer occurs between the greenhouse and the ground. Additionally, the Aurora Variable Speed Control can command that the auxiliary heaters turn on if the heat pumps cannot provide enough heat for the greenhouse. The Aurora Variable Speed Control can also control the air flow within the greenhouse and humidity by adjusting the blower speed within the heat pump. Additional control systems may need to be added to the rest of the HVAC system which is outside the scope of this design project.

2.5.5 Geothermal System Design Summary

The details of the geothermal system design are summarized below in TABLE V.

TABLE V - GEOTHERMAL SYSTEM DESIGN SUMMARY

Parameter	Value
Geothermal Configuration	Horizontal Closed Loop
Heat Pump	Two WaterFurnace 7 Series 700A11 Heat Pumps
Heat Pump Capacity	48000 BTU/h
Flow Center	Two GRUNDFOS UPS40-240, 230 V pumps
Minimum Ground Loop Flow Rate	5.46 gpm
Pipe Diameter	1.25 in
Total Pipe Length	2700 m
Heat Transfer Fluid	20 wt% propylene glycol, 80 wt% water mixture
Minimum Ground Temperature	0.87°C
Maximum Ground Temperature	8.45°C
Auxiliary Heater	Two EAL(H)15 Heaters
Control System	Aurora Variable Speed Control
Cost of Geothermal System	$71300

2.6. COMSOL Multiphysics Simulations

COMSOL Multiphysics simulations were performed to evaluate the transient response of the geothermal field and to validate that an appropriate ground temperature could be reached with the passive greenhouse design. Furthermore, the pipe material, pipe diameter and pipe length were verified to meet the required ground temperature to heat the greenhouse to 21°C ± 3°C year-round in Manitoba.

2.6.1 Assumptions

Due to the complex nature of the geothermal field, the following assumptions were made to simplify the analysis.

- 2D model
- Constant ground temperature of 2.5°C
- Water used as the heat transfer fluid
- Constant soil properties

- Exclusion of piping above the horizontally oriented pipes
- Averaged monthly heat loads

Using a 2D model assumes that the heat transfer between the geothermal field and the greenhouse is uniform at every point along the piping. Using a 2D model was performed due to computational limitations. However, the 2D model was deemed acceptable as the model would represent the average temperature of the ground around the horizontally oriented pipes which is also an accepted method in industry [60].

A constant ground temperature of 2.5°C based on a map provided by Rob Sinclair which showed the constant ground temperatures within Canada [50]. A constant ground temperature was assumed to be achieved at depths greater than 5 m [61].

Water was used as the heat transfer fluid within the simulation instead of the properties of a 20 wt% propylene 80 wt% water mixture. The assumption was deemed acceptable as the difference in properties such as density and heat capacity between water and the mixture were deemed negligible.

Constant soil properties were assumed to simplify the analysis. However, the soil properties in practice would not be uniform. The default soil properties in COMSOL Multiphysics were used for the purposes of the geothermal simulation. The soil properties (ie. water and air content) have a major impact on the heat transfer between the geothermal field and greenhouse which will need to be verified prior to the construction of the greenhouse.

Due to the chosen pipe depths of 20 ft and 25 ft to below the level at which a constant ground temperature is achieved (5 m), the pipes must be installed through horizontal boring. At these depths, the pipes cannot be installed with trenches and therefore, additional lengths of piping due to the entrance angle required for horizontal boring must be added. However, the COMSOL Multiphysics simulation was limited to investigate the heat transfer within the horizontally oriented sections of the ground loop. Heat losses within the diagonally and vertically oriented pipe sections are expected in practice but were excluded within the analysis and can be minimized using insulation.

Averaged monthly heating and cooling loads were used within the analysis. Although heating and cooling loads will depend on the time of day, available solar energy and outdoor temperature, the averages were deemed acceptable as any extremes would be levelled out over time. For more information about the heating and cooling loads, see Section 2.3.3 Layout Heat Losses.

2.6.2 Model

The area of interest was limited to a 5 m height by 6 m width section. The area represents a cross section where the fluid flows within the pipes perpendicular to the cross section. Since the geometry is the same across the pairs of boreholes, only two loops were required to be modeled (one loop at the 20 ft depth and one loop at the 25 ft depth). The top of the cross section at the 5 m height is located 5 m below ground level where constant ground temperatures are expected (therefore, the 0 m height is at a location of 10 m below ground). The 6 m width section was chosen based on the maximum recommended distance between each of the boreholes [62]. The center distance between the pipes in the same loop were established based on a HDPE fusion fitting and the thickness of the pipe was set based on common HDPE pipe sizes [63], [64]. A fine mesh with 4914 elements was applied to the geometry as shown in simulation. Figure and Figure 14. The red oval in Figure 13 is the zoomed-in area in Figure 14.

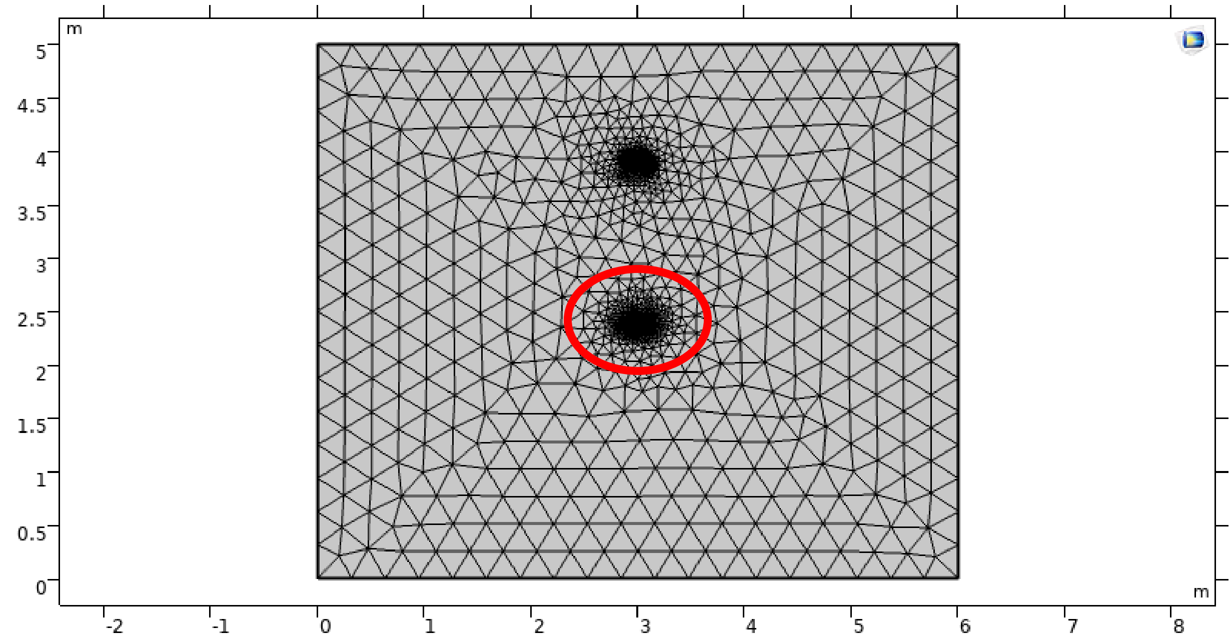

Figure 13 - Mesh across the global geometry of the simulation.

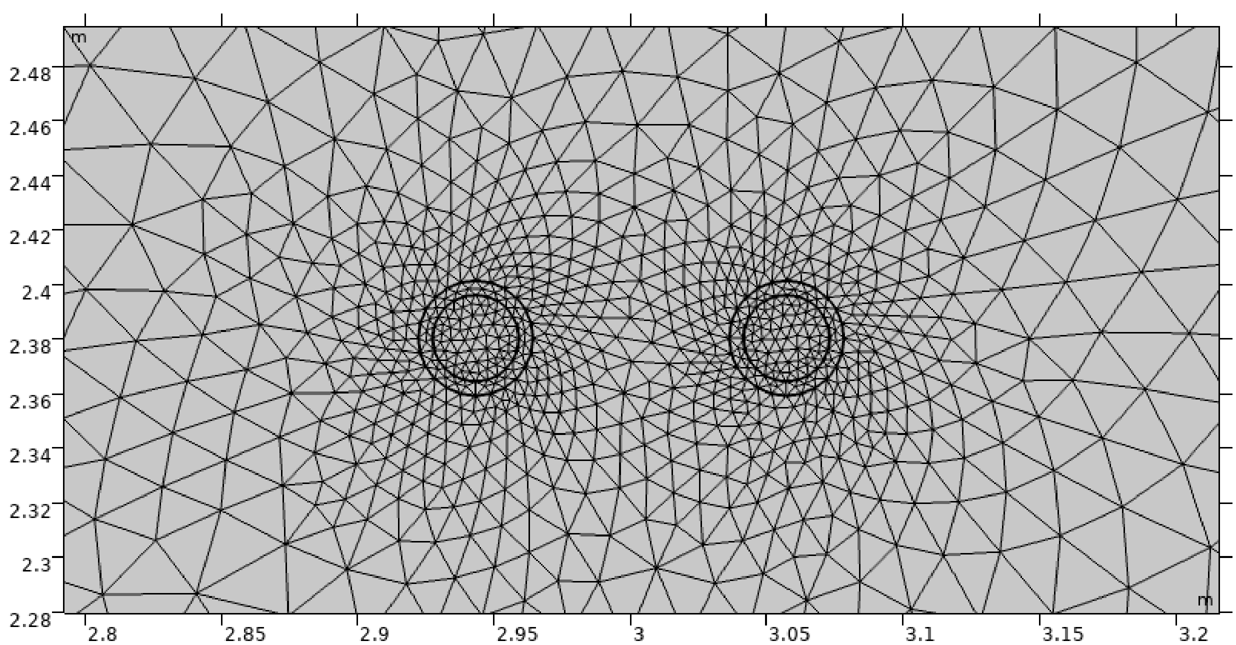

Figure 14 - Close-up of automatically adjusted mesh around the pipes.

The default soil properties for soil, water and HDPE were applied to the model in the appropriate locations. A thermal insulation boundary condition on the leftmost and rightmost surface of the soil were applied based on the symmetry condition between the boreholes. A constant temperature of 2.5°C was applied as the initial condition for the soil temperature and to the top and bottom surfaces of the soil based on the estimated constant temperature of soil in Shamattawa. The fluid temperature within the pipes were either -1.1°C when the heat pump was in heating mode or 30°C when in cooling mode [38]. The heating and cooling loads were applied as a heat flux from the inside of each of the pipes based on the previously calculated building heat and cooling loads for each month of the year. The first month of the analysis was set to be September as September was the latest that the greenhouse construction could be completed by to store enough heat in the ground for the winter season based on the heat load calculations.

2.6.3 Results

The simulation was performed over a period of 366 days, with a timestep of 1 day, to validate that the geothermal field would be able to extract heat year-round to meet the heating requirements of the greenhouse and would not have frozen pipes at any point. The temperature distribution across the whole model on day 1, day 122, day 305 and day 366 are shown in Figure 15, Figure 16, Figure 17, Figure 18. These temperature of the soil on these dates were selected to demonstrate the overall temperature increase over one year, as well as the temperature of the soil when the heating load and cooling loads of the greenhouse are at its highest.

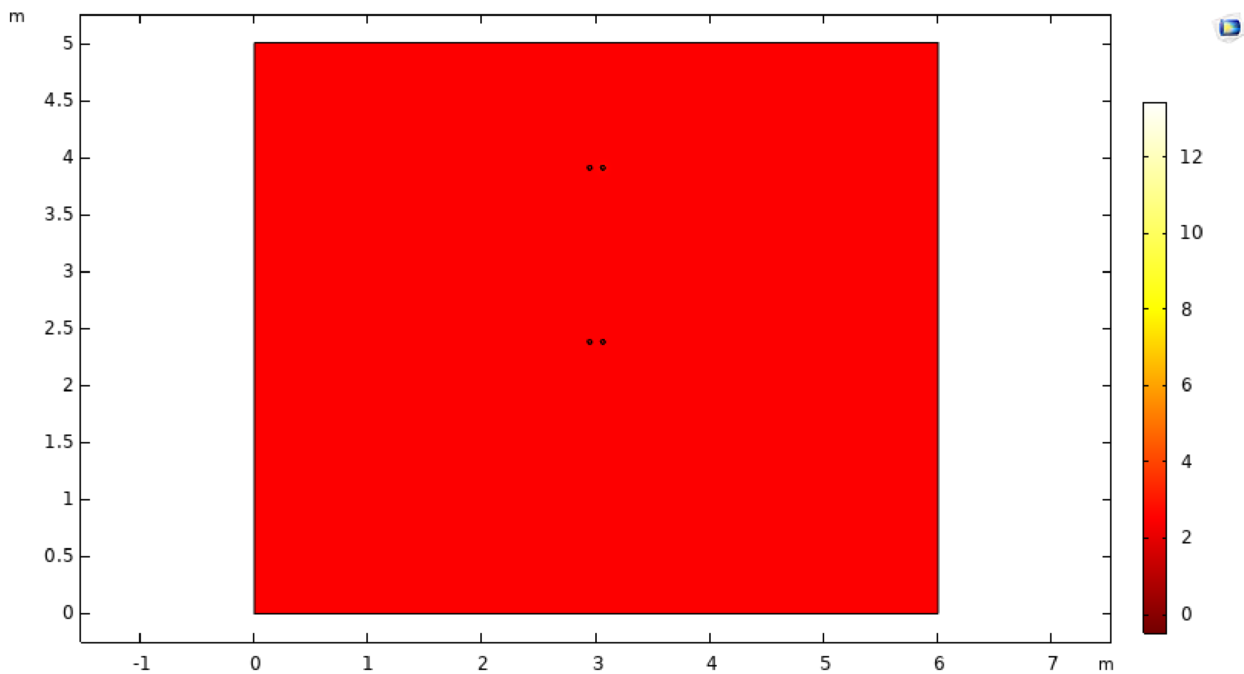

Figure 15 - Temperature distribution on day 1 (beginning of September) of the simulation, temperature units are in °C.

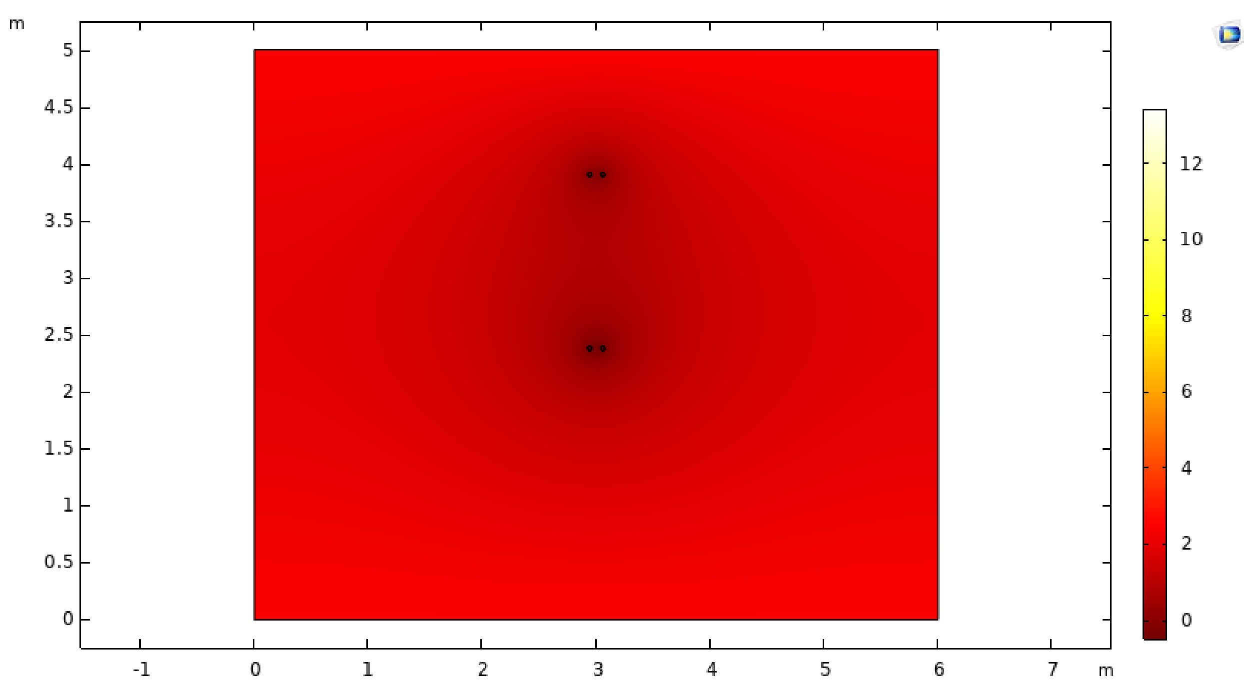

Figure 16 - Temperature distribution on day 122 (end of January) of the simulation, temperature units are in °C.

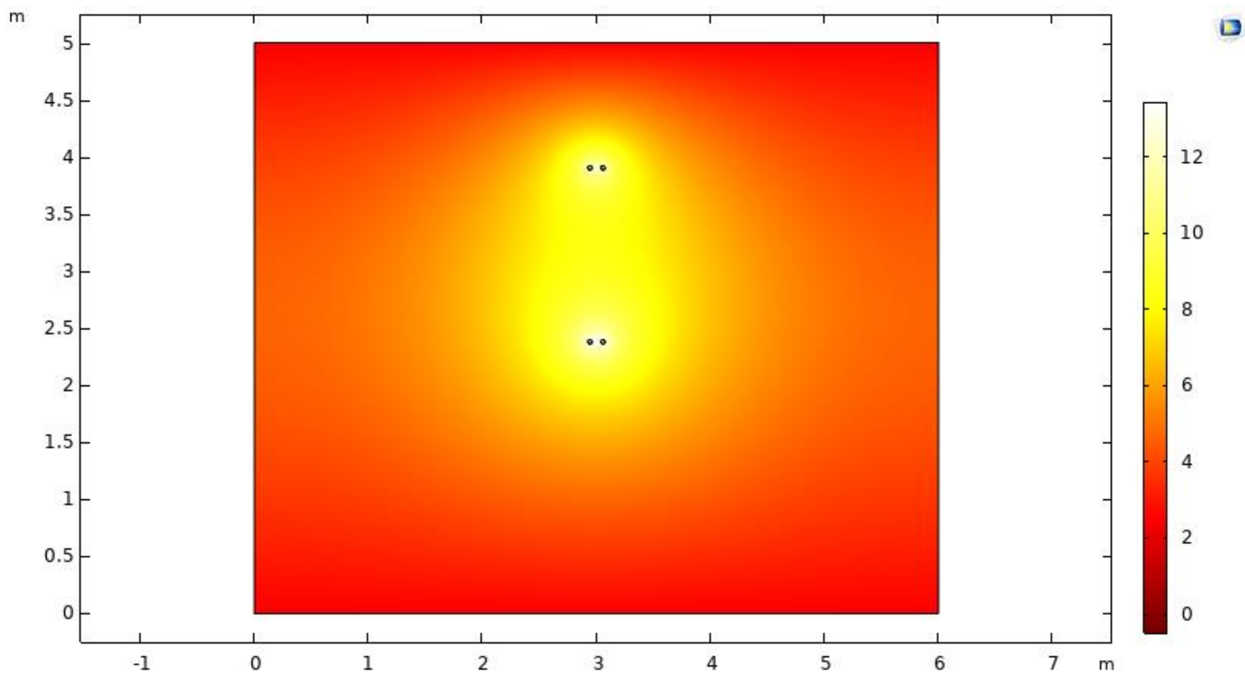

Figure 17 - Temperature distribution on day 305 (beginning of July) of the simulation, temperature units are in °C.

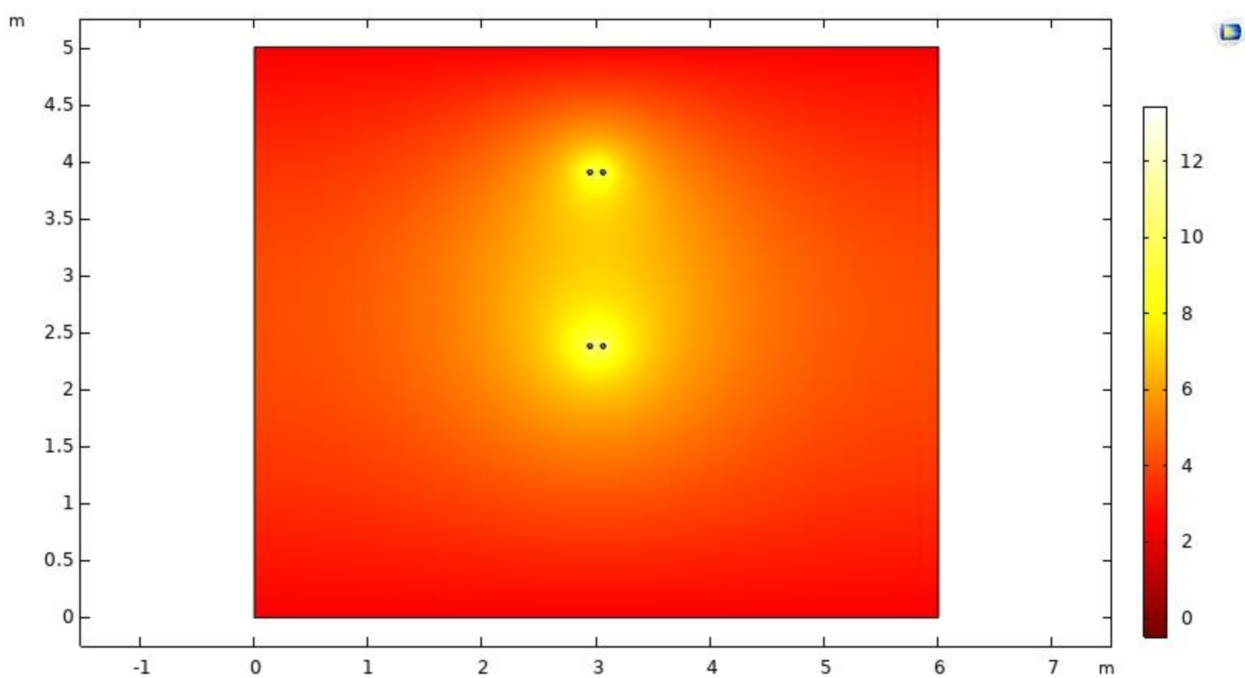

Figure 18 - Temperature distribution on day 366 (beginning of September) of the simulation, temperature units are in °C.

The temperature at a specific point (x = 3 m, y = 3.142 m) in between the loops was taken at each day of the simulation. The temperature of the soil between the loops over one year is shown in Figure 19.

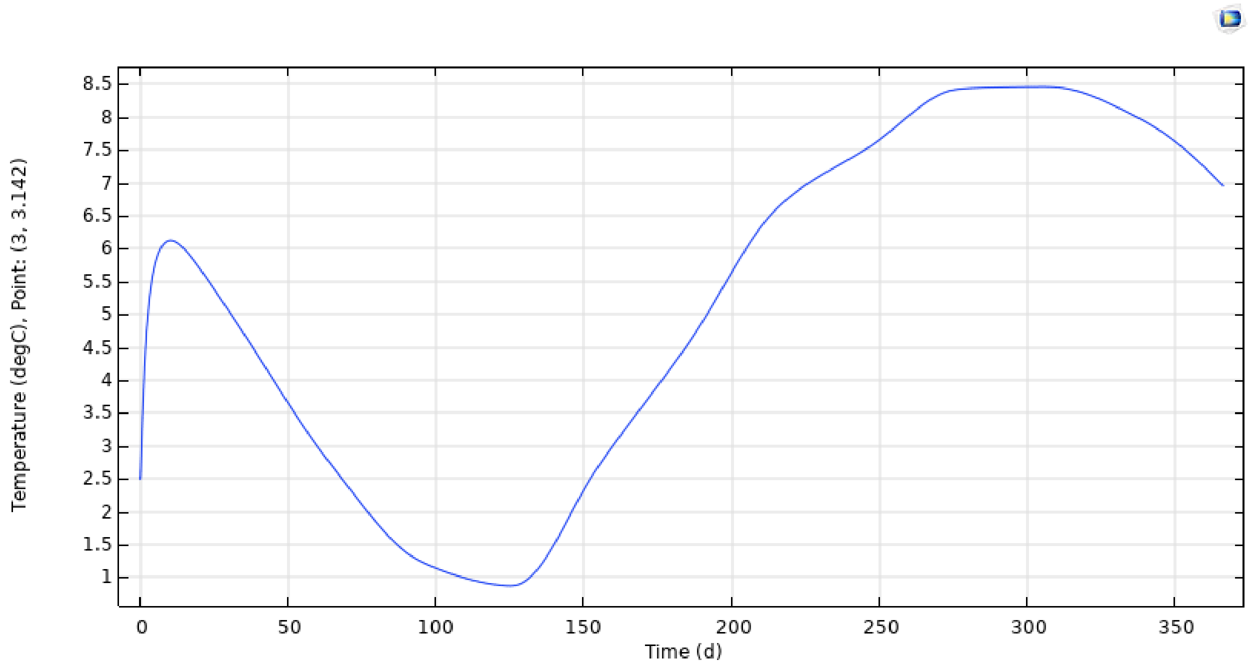

Figure 19 - Temperature of the soil over 1 year between the two loops.

2.6.4 COMSOL Multiphysics Simulation Discussion

From Figure 19, the temperature between the two loops ranges from 0.87°C to 8.45°C over the course of one year. Although the target specification for the ground temperature of 6.5°C to 15°C was not maintained throughout the whole year, the geothermal field loop sizing was deemed an acceptable size as the ground temperature never went below -1.1°C, the minimum temperature for the heat pump to extract heat from the ground. Therefore, the propylene glycol/water mixture would not be at risk of freezing. The simulation looked at the transient heat transfer response over the course of one year. However, from the heat load calculations, we know that the greenhouse on average can store 169823 kWh of energy into the ground per year. Therefore, over the lifespan of the greenhouse and geothermal system, the temperature of the ground which the geothermal system is extracting and storing heat from will increase every year. Recall that there are numerous limitations to the simulation discussed in Section 2.6.1 Assumptions, however, the simulation shows that the passive heat gain from the greenhouse has the potential to be stored into the ground to maintain the heating and cooling loads of the greenhouse year-round. The COMSOL Multiphysics simulation showed that the total length of the horizontally oriented sections of 2000 m was acceptable from a heat transfer perspective. Details of a mesh analysis can be found in Appendix C.

2.7. Installation Schedule

This section will be providing an estimate in the necessary time that it would take to build the greenhouse and install all the necessary components. The estimated time for installation mentioned early in this report were gathered and the resulting timeline can be seen below in Figure 20 - Installation Timeline. A full Gantt chart can be seen in Appendix C.

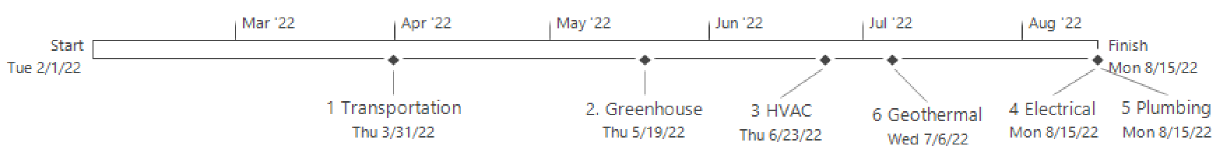

Figure 20 - Installation Timeline

For this installing schedule, there were some assumptions that were made. These assumptions are as follows:

- Assuming no delays, either to weather or any other issues that may occur
- Assuming that there are no issues with equipment or materials
- Assumed that all HVAC, plumbing and electrical work would begin after the greenhouse structure is complete.
- Assuming that tasks do not interfere with one another. For examples, this means that the work being done with the electrical section wouldn't interfere with the work being done in the plumbing section. With a more detailed design and speaking with contractors, a more accurate schedule could be made to avoid any issues.

- Tasks will be done in a linear fashion. This assumption assumes that tasks will be started and will be the only focus until it is complete. This may not be a realistic assumption as some tasks may have some down time associated with them. This is another area where speaking with contractors and having more detailed design will result in a more accurate schedule.

The first step for this project will be to transport all the necessary materials and supplies to Shamattawa using the winter roads. Since the winter roads are only accessible in late winter, the project cannot start until the roads are fit for use. As mentioned above, this is an area where weather can play a major role in whether or not this project can be completed on time. The next step will be to construct the greenhouse. Weather may also play a role in the time required to complete this task as bad weather may result in delays in the construction of the building. With the HVAC, plumbing and electrical work are assumed to be dependent on the completion of the building, it will be vital to project that the construction is completed on time with minimal delays.

2.8. Cost Analysis

2.8.1 Summary of Total Cost

Gathering all the cost mentioned in the previous sections, a total cost of the greenhouse was determined to be $1854210.00 CAD without taxes. A break down and summary of these costs can be seen below in

TABLE VI. These costs factor in the cost of the materials, the cost of the installation and the cost to transport materials to the build site. These costs were based on some basic research and previous completed projects that were similar in size. It should be mentioned that this is a basic cost estimation and if the greenhouse were to be built, a more in-depth cost analysis would be required. Also, further analysis and optimization would be required to ensure that the greenhouse could be designed as efficiently as possible. The goal would be to reduce cost wherever possible without sacrificing any performance and still meeting the needs of the client.

TABLE VI - COST SUMMARY

Structure	Cost [$]
Excavating	125000
Foundation and Concrete	250000
Framing	350000
Siding and Roof	300000
Southern Glass Wall	102000
Thermal Blankets	15000
Total	1142000
HVAC	Cost [$]
Tempeff High Efficiency HRV	80000
HVAC Control System	45000
Ductwork, Grilles, Bents, etc.	20000
Air Balancing	15000
Travel and Accommodations	7000
Total	167000
Electrical	Cost [$]
LEDs	14500
Lighting for Common Area	10000
Solar Panels	74000
Wind Turbines	71400
Batteries	73710
Fire Alarms and Exit Signs	25000
Power Supply to Building	40000
Power Supply to Mechanical Equipment	25000
Miscellaneous Electric Power	15000
Travel and Accommodations	20000
Total	368610
Plumbing	Cost [$]
Filters	1500
Water and Sewer	20000
Basic Plumbing	40000
Irrigation System	20000
Water Storage	3800

Travel and Accommodations	20000
Total	105300
Geothermal	Cost [$]
Horizontal Boring	40000
Piping/Plumbing	12000
Heat Pumps	12000
Flow Center	2300
Auxiliary Heaters	5000
Total	71300
Grand Total	1854210

2.8.2 Solar Panel and Wind Turbine Economic Feasibility

One of the main reasons why solar panels and wind turbines were requested by the KGS Group to consider was because of the high service rate for electrical services for communities that are reliant on diesel generating stations. The total installation costs for the renewable energy sources were $219110. The current general service electrical rate from diesel generating stations is a basic monthly charge of $20.64, 9.263 cents/kWh for the first 2000 kWh and 42.617 cents/kWh for each kWh exceeding 2000 kWh [65]. Recall that the average daily electrical load of the greenhouse is 529 kWh per day. If the greenhouse were solely powered through the diesel generating station, the greenhouse would cost approximately $74530 per year to operate. If the greenhouse were operated only using power from the diesel generating station, the electrical costs would be one of the greatest operating costs for the greenhouse. Assuming the greenhouse can rely on the renewable energy sources for most of the year which is dependent on weather conditions and reliability of the renewable energy equipment, the inclusion of renewable energy sources with the greenhouse becomes a favorable economic decision in as little as 2.93 years. Which is when the cost of installing the renewable energy sources is lower than the total operation costs of running the greenhouse off diesel generated electricity.

2.8.3 Cost of Diabetes and Obesity

The costs associated with health issues, such as diabetes and obesity, can be reduced within a community by introducing resources that reduce the costs of healthier food options [66]. Within Manitoba First Nations communities, the rate of diabetes is 3 to 5 times higher than that of the general population [67]. Annual health-related costs associated with diabetes and obesity are as follows [68]:

- Type 1 diabetes on multiple daily insulin injections: $800 to $3,100
- Type 1 diabetes on insulin pump therapy: $2,200 to $6,200
- Type 2 diabetes on oral medication: $1,900
  Individuals suffering from obesity: $1,453

An emergency flight, from Shamattawa to Winnipeg, can cost upwards of $750-$900 [69], with an additional $800 cost for an ambulance [70].

By introducing a geothermal greenhouse, that can drastically reduce the costs of healthy food options, the diets of remote communities would likely improve, and help to prevent the aforementioned costs.

3. Conclusions and Recommendations

A summary of the key features of the geothermal greenhouse design, how the geothermal greenhouse design meets the objectives set by the client and future recommendations on how to proceed with the design of the geothermal greenhouse are discussed within this section.

3.1 Summary of Geothermal Greenhouse Design

The main features of the geothermal greenhouse design are summarized below.

- Location: Shamattawa First Nations, MB
- Passive Heating/Geothermal System
- Thermally balanced

- Horizontal closed geothermal loop
- Community area
- Use of IMP
- Renewable energy sources

The geothermal greenhouse is to be in Shamattawa First Nations as the community is reliant on one of four diesel generating stations, lacks summer road access and as a result, has relatively high food costs. Furthermore, Shamattawa geological data was available to the group to base the geothermal calculations on.

Through heat load calculations, the greenhouse will generate excess heat every year due to the transparent south facing wall which has been designed to maximize radiation heat energy gained of the greenhouse. The greenhouse has a net positive heat gain of up to 169823 kW per year. The excess heat generated passively will be stored in the ground with the use of two WaterFurnace Series 7 700A11 heat pumps and can consistently maintain a building temperature of 21°C ± 3°C throughout the year, verified using a COMSOL Multiphysics heat transfer simulation.

As heat is injected into the ground on an annual basis, the geothermal field will be able to extract heat from the ground continually over the course of the minimum 20-year lifespan of the greenhouse. The geothermal field consists of a horizontal closed loop system.

A specific area within the greenhouse was designated for a community area for people to gather. The space allocation of a community area within the greenhouse was done to provide social and mental health benefits of community members.

Use of insulated metal panels (IMP) was chosen due to the large R-values that could be achieved with minimal space, their ease of installation and they limit the chances of having condensation problems within the greenhouse.

The last main feature of the greenhouse is that most of the electrical loads will be supplied with the use of renewable energy sources such as solar panels and wind turbines. Having both solar and wind sourced energy reduces the chances of the greenhouse not having power from either of these sources due to the weather conditions and reduces the reliance on diesel generated electricity.

3.2 Benefit to the Client

Recall that the overall project objective was to design and assess the feasibility of a geothermal greenhouse in northern Manitoba to improve access to healthy foods in these communities. A design has been provided which shows that the greenhouse is physically feasible to operate in Manitoba's harsh weather conditions year-round which was shown through analytical calculations, facility layout model and COMSOL simulations. Although the economic and social feasibility of implementing a geothermal greenhouse was preliminarily investigated in this report, further investigation is necessary to definitively confirm that constructing a geothermal greenhouse in northern communities would be favorable from an economic and social standpoint. Nevertheless, Team 3 has provided a potential geothermal greenhouse design that is thermally balanced and can gain enough heat energy to sustain the greenhouse temperature year-round. The KGS Group can take the information provided in this report to optimize aspects of the greenhouse design to improve the economic feasibility of implementing the greenhouse.

The final greenhouse specifications are summarized in TABLE VII. Note that although the minimum storage temperature is below the target value of 6.5°C, 0.87°C was deemed acceptable based on the heat pump and heat transfer fluid properties. To reiterate, the actual specifications shows that the greenhouse is safe, can operate in Manitoba's harsh temperatures and weather conditions, can grow plants year-round, is interactive and community based, has the potential to be economically viable, is environmentally friendly, appropriately sized, comfortable to work in and can operate for at least 20 years.

TABLE VII - FINAL GREENHOUSE SPECIFICATIONS

Metric	Units	Target Specs	Actual Specs

Internal greenhouse temperature	°C	20 ± 3	20 ± 3
Storage temperature	°C	6.5-15	0.87-8.45
Light duration	hours	12-18	18
Daily light integral	mol/m2/day	12	15
Air exchanges	air exchanges/hour	2-180	2-180
Relative humidity	%	70-80	70-80
Inclusion of a community space	binary	pass	pass
Installation costs of geothermal system	$	<100000	71300
Integration of renewable energy sources	Binary	pass	pass
Dimensions	m^2	<4800	500
Service life of materials and components	years	20	20

3.3 Recommendations

If the geothermal greenhouse were to be implemented within a community, one of the most important tasks would be to perform test drilling or tests on the soil properties. The soil properties used within this report were assumed and have a major impact on the heat transfer between the ground loop and surrounding soil.

The design also needs to be adjusted to meet all relevant building codes such as the Manitoba Building Code. Considerations such as the loads that the building must withstand such as snow and wind loads are an example of a relevant building code that needs to be addressed prior to the implementation of the geothermal greenhouse. Further design work related to the general plumbing, HVAC and electrical systems need to be considered as well.

Due to the scope of the capstone course, Team 3 did not get a chance to interact with members in northern communities. Getting the community input and approval is paramount to the successful installation of a geothermal greenhouse in northern Manitoba. Although design features were implemented with the community in mind, ie. the community area, working with the community directly would be the best way to establish what they want and require from a geothermal greenhouse.

More research can be done on plant specific requirements (such as pollination, and pest control, etc.). As a team of mechanical engineering undergraduate students, the team recommends that someone more knowledgeable about growing plants are consulted with to provide recommendations for the geothermal greenhouse design to have favorable plant growth.

- Reducing water resources
- Operations (employment, waste produce, produce storage)
- Solar Ponds

As water resources are a major issue in many First Nations communities, further investigation on reducing the amount of water used in the greenhouse or methods to collect rainwater should be performed to reduce unnecessary water usage.

General operations of the greenhouse such as employment to keep the greenhouse running or produce storage (both consumable and waste produce) were not considered within this report. A plan for the general operations for the greenhouse can help KGS decide if the greenhouse is economically viable.

In the case of our design of a geothermal greenhouse located in Shamattawa, excess heat was able to be produced through passive means. If there was not enough heat that could be supplied, other heat sources could be implemented with the greenhouse design. Examples of potential heat sources include solar panels that heat fluid, waste heat from a diesel generating station, heat from a standing body of water and solar ponds.

Although the presented geothermal greenhouse design must be adjusted for all the reasons listed above, Team 3 has presented a preliminary geothermal greenhouse design for the KGS Group to move forward with if they choose.

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Appendix A – Head Loss Calculations for Determining Geothermal Field Piping Length

The minor and major head losses were calculated using a spreadsheet from McGraw-Hill Global Education Holdings, LLC and is shown below with written permission to use the spreadsheet within this report [56]. The spreadsheet was used to verify if the minimum flow rate for the heat pump of 5 gpm could be achieved with the total head of the pumps and head losses throughout the system.

Selection of Liquid and Setting the Density and Viscosity values for use in the other Worksheets

MAKE CHOICES

Click on the yellow cell below and then on the arrow to the right of it to select either the Fanning or Moody friction factor for your calculations in this workbook.

Moody

Click on the yellow cell below and then on the arrow to the right of it to select either lbm or slugs to be used in your calculations in this workbook.

lbm

LIQUID DENSITY

Either (i) select a liquid and enter its temperature in the first two yellow cells below, so that its density & viscosity will be calculated and used, or else (ii) enter liquid density in cell D37 and viscosity in cell D53 and those values will be used.

(Enter Values in yellow cells only)

Select a Liquid and Enter Temperature	
Click at right to Select Liquid	Water
Temperature Range (°F):	32 to 176
Liquid Temperature (°F):	30
Liquid Density (lbm/cu ft)	62.62

NOTE: If you want to use a liquid from the menu above, then the yellow cell, D37 must be blank.

For densities of selected fuels and lubricants, see Mark's Standard Handbook for Mechanical Engineers, 12th Ed., Table 1.3.1

Use the density value above, OR

Enter a Liquid Density Obtained Elsewhere	
Liquid Density (lbm/cu ft)	63.8

Liquid Density Result:	**63.8**	**lbm/cu ft**	**(manual entry)**
	1.983	slugs/ft^3	

(This is the density value that will be used in all of the other worksheets.)

LIQUID VISCOSITY

Viscosity from above menu selection:	
0.0000367	lbf-s/ft^2

NOTE: If you want to use a liquid from the menu above, then the yellow cell, D53 must be blank.

For viscosities of selected fuels and lubricants, see Mark's Standard Handbook for Mechanical Engineers, 12th Ed., Table 1.3.3

Use the viscosity value above, OR

Enter a Liquid Viscosity Obtained Elsewhere	
Liquid Viscosity (lbf-s/ft^2):	6.23681E-05

Liquid Viscosity Result:	**6.24E-05**	**lbf-s/ft^2**	**(manual entry)**

(This is the viscosity value that will be used in all of the other worksheets.)

Calculation of the Sum of the Minor Loss Coefficients

Enter K values for up to 20 fittings in the yellow cells below. Leave excess yellow cells blank.

INPUT K VALUES

	Minor Loss Coefficient, K
Fitting #1	0.04
Fitting #2	0.04
Fitting #3	1.8
Fitting #4	18
Fitting #5	18
Fitting #6	0.04
Fitting #7	0.04
Fitting #8	300
Fitting #9	
Fitting #10	
Fitting #11	
Fitting #12	
Fitting #13	
Fitting #14	
Fitting #15	
Fitting #16	
Fitting #17	
Fitting #18	
Fitting #19	
Fitting #20	
ΣK	**337.96**

NOTE: Some minor loss coefficients depend on the value of Re or pipe diameter. If that is the case for any of your K values, you may need to make one or two iterations of updating the K value(s) on this worksheet after seeing the value(s) of Re and/or D from the Flow Rate or Diameter worksheet.

Current value of Re for

Flow Rate Worksheet:	4728
Diameter Worksheet:	4330
Press. Drop Worksheet:	4330

Current value of pipe diameter for Diameter Worksheet: 1.1 in

Additional Sources of Information on Minor Loss Coefficients:

Perry's Chemical Engineer's Handbook, 9th Ed, Sec 6.1.5

Piping Calculations Manual, Sec 3.7, Minor Losses

Stormwater Collection Systems Design Handbook, Sec 12.2.1.2

Source for values in the table below: Perry's Chemical Engineer's Handbook, 9th Ed, Table 6-5

Minor Loss Coefficients for Turbulent Flow through Fittings and Valves

Fitting	Minor Loss Coefficient	Fitting	Minor Loss Coefficient
45^o ell, standard	**0.35**	Globe valve, plug disk, open	**9**
45^o ell, long radius	**0.2**	Globe valve, plug disk, 3/4 open	**13**
90^o ell, standard	**0.75**	Globe valve, plug disk, 1/2 open	**36**
90^o ell, long radius	**0.45**	Globe valve, plug disk, 1/4 open	**112**
90^o ell, square or miter	**1.3**	Angle valve, open	**2**
180^o bend, close return	**1.5**	Y or blowoff valve, open	**3**
Tee, standard, along run, branch blanked off	**0.4**	Plug cock, $\theta = 5^o$	**0.05**
Tee, standard, used as ell, entering run	**1**	Plug cock, $\theta = 10^o$	**0.29**
Tee, standard, used as ell, entering branch	**1**	Plug cock, $\theta = 20^o$	**1.56**
Tee, standard, branching flow	**1**	Plug cock, $\theta = 40^o$	**17.3**
Coupling	**0.04**	Plug cock, $\theta = 60^o$	**206**
Union	**0.04**	Butterfly valve, $\theta = 5^o$	**0.24**
Gate valve, open	**0.17**	Butterfly valve, $\theta = 10^o$	**0.52**
Gate valve, 3/4 open	**0.9**	Butterfly valve, $\theta = 20^o$	**1.54**
Gate valve, 1/2 open	**4.5**	Butterfly valve, $\theta = 40^o$	**10.8**
Gate valve, 1/4 open	**24**	Butterfly valve, $\theta = 60^o$	**118**
Diaphragm valve, open	**2.3**	Check valve, swing	**2**
Diaphragm valve, 3/4 open	**2.6**	Check valve, disk	**10**
Diaphragm valve, 1/2 open	**4.3**	Check valve, ball	**70**
Diaphragm valve, 1/4 open	**21**	Foot valve	**15**
Gate valve, 1/4 open	**24**	Water meter, disk	**7**
Globe valve, bevel seat, open	**6**	Water meter, piston	**15**
Globe valve, bevel seat, 1/2 open	**9.5**	Water meter, rotary (star-shaped disk)	**10**
Globe valve, composition seat, open	**6**	Water meter, turbine wheel	**6**
Globe valve, composition seat, 1/2 open	**8.5**		

Minor Loss Coefficient for sharp-edged entrance with turbulent flow:

Perry's Chemical Engineer's Handbook, 9th Ed, Eqn 6-90

$K = 0.5[1 - (A_2/A_1)]$

Pipe Flow - Frictional Pressure Drop/Head Loss: (U.S. units)

Calculation of Frictional Pressure Drop & Head Loss (including minor losses) for given flow rate, Q, pipe diam, D, pipe roughness, ε, and liquid properties, ρ & μ, using the Moody friction factor

NOTE: This worksheet is set to use the Moody friction factor for all calculations. If you want to use the Fanning friction factor instead, go to the top of the Fluid Properties worksheet to make the change.

INPUT DATA

Enter the indicated input data:

(Enter Values in Yellow Cells Only)

Pipe Diameter, D_{in} =	1.25	in
Pipe Length, **L** =	8858	ft
Pipe Roughness, ε =	0.00007	ft
Pipe Flow Rate, **Q** =		cfs
OR	5	gpm
Q =	**0.01114082**	cfs
Sum of Minor Loss Coefficients, **ΣK** =	337.96	

Calculated Values:

Pipe Diameter, **D** =	0.1042	ft
Cross-Sect. Area, **A** =	0.0085	ft^2
Ave. Velocity, **V** =	1.3	ft/sec

From Liquid Properties Worksheet:

Liquid for Calculations:	Water
Temperature of Liquid (^oF):	30

CALCULATIONS

Friction Factor Calculation

Reynolds Number, Re =	4.330E+03
Moody Friction Factor =	0.039686

NOTE: For turbulent flow,
The Moody friction factor is calculated behind the scenes (in cells C68:D84) with the Colebrook equation using an iterative calculation.

Pressure Drop Calculations
ΔP_f and h_L

Pressure Drop, ΔP_f =	6291.82773	psf
Pressure Drop, ΔP_f =	**43.6932481**	**psi**
Frictional Head Loss, h_L =	**98.6179895**	**ft**

Discussion and References

Information about the friction factor, as well as useful equations, tables, and figures:

Perry's Chemical Engineers' Handbook, 9th Ed. - Section 6.1.4
Hick's Handbook of Chemical Engineering Calculations, Fourth Ed. - Section 6.4
Mark's Standard Handbook for Mechanical Engineers, 12th Ed. - Section 1.3.10
Ricketts' Standard Handbook for Civil Engineers, 5th Ed. - Section 21.3

Figures and Equations

The friction factor chart, which is being replaced by this spreadsheet as a means of obtaining a value for the friction factor for known values of the Reynolds number and ε/D:

Perry's Chemical Engineer's Handbook, 9th Ed, Figure 6-9 - Fanning Chart
Mark's Standard Handbook for Mechanical Engineers, 12th Ed, Fig 1.3.24 - Moody Chart

Tables of roughness, ε, for various pipe materials:
Perry's Chemical Engineer's Handbook, 9th Ed, Table 6-2 - S.I. units
Mark's Standard Handbook for Mechanical Engineers, 12th Ed, Table 1.3.9 - U.S. units

Friction Factor Equations

For Laminar Flow: **Fanning friction factor = 16/Re** ; **Moody friction factor = 64/Re**

For Turbulent flow:

The Churchill Equation: $\mathbf{f = \{-4 \log[(0.27\varepsilon/D) + (7/Re)^{0.9}]\}^{-2}}$ [with Fanning Friction Factor]

The Churchill Equation: $\mathbf{f = \{-2 \log[(0.27\varepsilon/D) + (7/Re)^{0.9}]\}^{-2}}$ [with Moody Friction Factor]
(The Churchill Eqn is used in this worksheet to get an initial assumed value of f for turbulent flow.)

The Colebrook Equation: $\mathbf{f = \{(-4)\log[(\varepsilon/3.7D) + (1.256/(Re*f^{1/2}))]\}^{-2}}$ [Fanning Friction Factor]

The Colebrook Equation: $\mathbf{f = \{(-2)\log[(e/3.7D) + (2.51/(Re*f^{1/2}))]\}^{-2}}$ [Moody Friction Factor]
(The Colebrook Eqn is used to get a final value of f for turbulent flow through an iterative calculation.)

Equations relating pipe flow parameters to each other with the friction factor

The Fanning Equation: Equation 6-31 in Perry's Chemical Engineer's Handbook, 9th Ed.
(with minor losses included)

$$4 f_f\left(\frac{L}{D}\right) + \Sigma K = \frac{2\,\Delta P_f}{\rho V^2}$$

$$f = \frac{D\,\Delta P_f}{2\,\rho V^2 L}$$

The Darcy Weisbach Equation: Equation 21-30 in the Standard Handbook for Civil Engineers, 5th Ed.
(with minor losses included)

$$h_L = \left[f_m\left(\frac{L}{D}\right) + \Sigma K\right]\left(\frac{V^2}{2g}\right)$$

The equation relating frictional pressure drop and frictional head loss: $\mathbf{h_L = \Delta P_f g_c/\rho g}$

$\mathbf{g_c = 32.174\ lbm\text{-}ft/lbf\text{-}sec^2 = 1\ slug\text{-}ft/lbf\text{-}sec^2}$

Following is a link to an example calculation similar to the one in this worksheet:

Handbook of Chemical Engineering Calculations, Fourth Ed, Section 6.4

Pipe Flow Rate Calculator (Moody friction factor): (U.S. units)

Calculation of Liquid Flow Rate, Q, for given frictional head loss, h_L, minor loss coeff's, ΣK, pipe diam., D, pipe length, L, pipe roughness, ε, and Liquid properties, ρ & μ.

NOTE: This worksheet is set to use the Moody friction factor for all calculations. If you want to use the Fanning friction factor instead, go to the top of the Liquid Properties worksheet to make the change.

INPUT DATA

Enter the indicated input data:

Pipe Diameter, D_{in} =	1.25	in
Pipe Length, **L** =	8858	ft
Pipe Roughness, ε =	0.00007	ft
Allowable Head Loss, h_L =	115	ft
Sum of Minor Loss Coefficients, ΣK =	337.96	
Assumed Flow Rate, Q_A:	0.012165	cfs

(enter an assumed value to start the iterative calculations)

(Enter Values in Yellow Cells Only)

From Liquid Properties Worksheet:

Liquid for Calculations:	Water
Temperature of Liquid (°F):	30

CALCULATIONS

Cross-Sect. Area, **A** =	0.0085	ft^2
Ave. Velocity, **V** =	1.42745	ft/sec
Reynolds Number, **Re** =	4.728E+03	
Moody Friction Factor	0.0387	
Calculated Velocity, **V** =	1.43	ft/sec
Calculated Flow Rate, Q_C:	0.012165	cfs
Difference, $(Q_A - Q_C)*10^3$ =	-0.0000303	cfs

NOTE: For turbulent flow, The Moody friction factor is calculated behind the scenes (in cells C70:D79) with the Colebrook equation using an iterative calculation.

Liquid Flow Rate =	**1.216E-02**	**cfs**
	5.460	**gpm**

NOTE: This is an iterative solution. You must use Excel's "Goal Seek" to find the flow rate as follows: Place the cursor on cell D34 and click on "goal seek" (in the "tools" menu of older versions and under "Data What If Analysis" in newer versions of Excel). Enter values to "Set cell:" D34, "To value:" 0, "By changing cell:" D20, and click on "OK". The calculated value of Q will appear in cells D20 & D38. Note that an initial assumed value for Q must be entered in the yellow cell D20 to start the process.

Discussion and References

Information about the friction factor, as well as useful equations, tables, and figures:

Perry's Chemical Engineers' Handbook, 9th Ed. - Section 6.1.4
Hick's Handbook of Chemical Engineering Calculations, Fourth Ed. - Section 6.4
Mark's Standard Handbook for Mechanical Engineers, 12th Ed. - Section 1.3.10
Ricketts' Standard Handbook for Civil Engineers, 5th Ed. - Section 21.3

Figures and Equations

The friction factor chart, which is being replaced by this spreadsheet as a means of obtaining a value for the friction factor for known values of the Reynolds number and ε/D:

Perry's Chemical Engineer's Handbook, 9th Ed, Figure 6-9 - Fanning Chart
Mark's Standard Handbook for Mechanical Engineers, 12th Ed, Fig 1.3.24 - Moody Chart

Tables of roughness, ε, for various pipe materials:

Perry's Chemical Engineer's Handbook, 9th Ed, Table 6-2 - S.I. units
Mark's Standard Handbook for Mechanical Engineers, 12th Ed, Table 1.3.9 - U.S. units

Friction Factor Equations

For Laminar Flow: **Fanning friction factor = 16/Re ; Moody friction factor = 64/Re**

For Turbulent flow:

The Churchill Equation: $f = \{-4 \log[(0.27\varepsilon/D) + (7/Re)^{0.9}]\}^{-2}$ [with Fanning Friction Factor]

The Churchill Equation: $f = \{-2 \log[(0.27\varepsilon/D) + (7/Re)^{0.9}]\}^{-2}$ [with Moody Friction Factor]

(The Churchill Eqn is used in this worksheet to get an initial assumed value of f for turbulent flow.)

The Colebrook Equation: $f = \{(-4)\log[(\varepsilon/3.7D) + (1.256/(Re*f^{1/2}))]\}^{-2}$ [Fanning Friction Factor]

The Colebrook Equation: $f = \{(-2)\log[(e/3.7D) + (2.51/(Re*f^{1/2}))]\}^{-2}$ [Moody Friction Factor]

(The Colebrook Eqn is used to get a final value of f for turbulent flow through an iterative calculation.)

Equations for calculating velocity:

With Fanning friction factor: $V = \{2gh_L/[4(fL/D + \Sigma K)]\}^{1/2}$ (from the Fanning equation with minor losses)

With Moody friction factor: $V = \{2gh_L/[(fL/D) + \Sigma K]\}^{1/2}$ (from Darcy Weisbach equation with minor losses)

Equation relating Q, V & D: $Q = V(\pi D^2/4)$

Following is a link to an example calculation similar to the one in this worksheet:

Mark's Standard Handbook for Mechanical Engineers, 12th Ed., Engineering Calculations: Case 2

The spreadsheet allowed us to calculate the head losses within the geothermal field and was an acceptable size based on the pump parameters.

Appendix B – COMSOL Multiphysics Mesh Analysis

A mesh analysis was performed on the COMSOL Multiphysics simulation to validate that the temperature results were converging to a single value as the number of elements were increased. The temperature at a location between the two loops (x = 3 m, y = 3.142 m) was measured on day 366 each time a simulation was performed, with each simulation having an increasing number of elements. Figure B. 1 shows the results from the mesh analysis and we observe that the temperature converged as there is little change as more elements are introduced within the mesh. Therefore, we have gained confidence in the temperature readings as the mesh analysis showed convergence, meaning that the elements within the model are of an appropriate size.

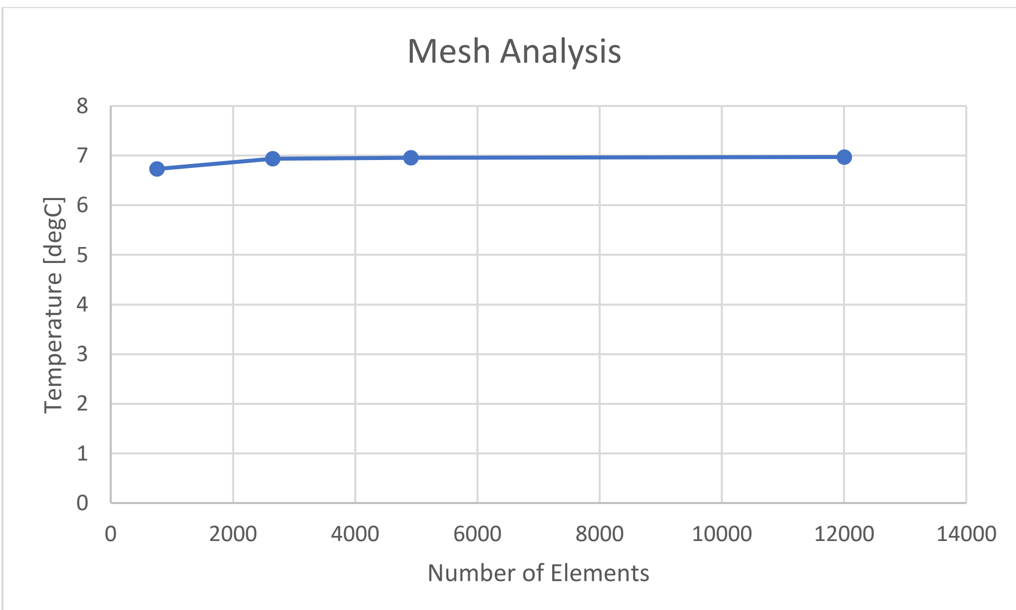

Figure B. 1 - Plot of results from the mesh analysis.

Appendix C - Gantt Chart

A Gantt chart showing the installation schedule for the geothermal greenhouse in northern Manitoba is shown below.

1 Transportation	43 days	Tue 2/1/22	Thu 3/31/22		Yes
2. Greenhouse	35 days	Fri 4/1/22	Thu 5/19/22	2	Yes
2.1 Excavating	5 days	Tue 4/26/22	Mon 5/2/22	2	No
2.2 Foundation and concrete	14 days	Tue 5/3/22	Fri 5/20/22	4	No
2.3 Framing	7 days	Mon 5/23/22	Tue 5/31/22	5	No
2.4 Siding and roof	7 days	Wed 6/1/22	Thu 6/9/22	6	No
2.5 Southern Glass wall	7 days	Wed 6/1/22	Thu 6/9/22	6	No
2.6 Thermal Blankets	3 days	Fri 6/10/22	Tue 6/14/22	8	No
3 HVAC	12 days	Fri 6/17/22	Mon 7/4/22	3	Yes
3.1 Ducts	3 days	Fri 6/17/22	Tue 6/21/22	3	No
3.2 Vents/Diffusers	3 days	Wed 6/22/2:	Fri 6/24/22	11	No
3.3 Fans	3 days	Mon 6/27/22	Wed 6/29/22	12	No
3.4 Control system	3 days	Thu 6/30/22	Mon 7/4/22	13	No
4 Electrical	42 days	Fri 6/17/22	Mon 8/15/22	3	Yes
4.1 General Electrical Work	14 days	Thu 6/16/22	Tue 7/5/22	3	No
4.2 Solar Panel	7 days	Wed 7/6/22	Thu 7/14/22	16	No
4.3 Wind Turbines	7 days	Fri 7/15/22	Mon 7/25/22	17	No
4.4 Batteries	7 days	Tue 7/26/22	Wed 8/3/22	18	No
4.5 LED's	7 days	Thu 8/4/22	Fri 8/12/22	19	No
5 Plumbing	42 days	Fri 6/17/22	Mon 8/15/22	3	Yes
5.1 General plumbing	14 days	Thu 6/16/22	Tue 7/5/22	3	No
5.2 Water holding tank	7 days	Wed 7/6/22	Thu 7/14/22	22	No
5.3 Irrigation system	7 days	Fri 7/15/22	Mon 7/25/22	23	No
5.4 Pump	14 days	Tue 7/26/22	Fri 8/12/22	24	No
6 Geothermal	10 days	Thu 6/23/22	Wed 7/6/22	3	Yes
6.1 Horizontal Boring	3 days	Thu 6/16/22	Mon 6/20/22	3	No
6.2 Piping/Plumbing	1 day	Tue 6/21/22	Tue 6/21/22	27	No
6.3 Heat Pumps	2 days	Wed 6/22/2:	Thu 6/23/22	27,:	No
6.4 Flow Center	1 day	Fri 6/24/22	Fri 6/24/22	29	No
6.5 Auxilliary Heaters	1 day	Sat 6/25/22	Sat 6/25/22	29	No
6.6 Control system	1 day	Mon 6/27/22	Mon 6/27/22	31	No

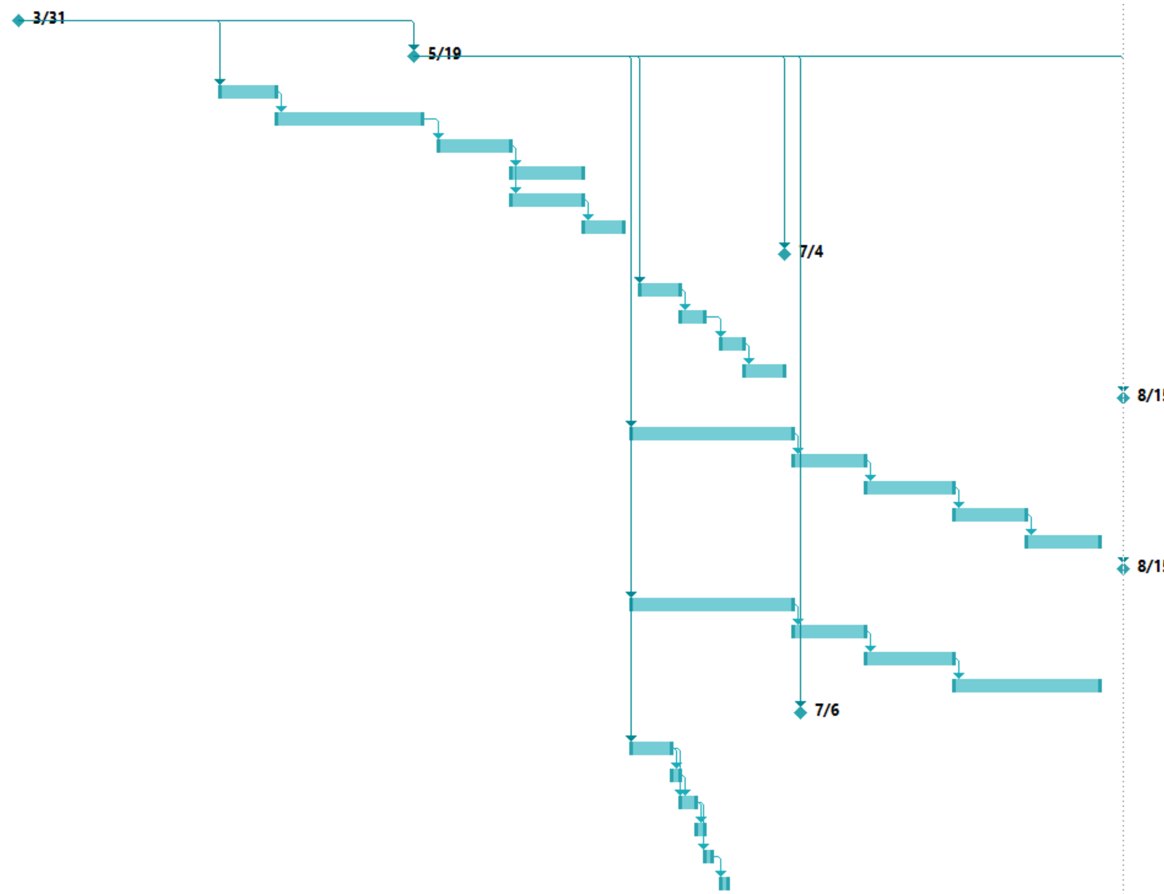

Figure C. 1 - Installation schedule for geothermal greenhouse project