Project Proposal and Feasibility Study

Team 13: GEOmelt

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Senior Design
December 11, 2009
Calvin College
Abstract

The project goal of team GEOmelt is to design a snowmelt system that uses geothermal energy to improve efficiency. Snowmelt systems increase safety for pedestrians and vehicles alike, and virtually eliminate the need for manual shoveling or plowing of snow. Geothermal energy is readily accessible year-round, and its ability to heat and cool buildings has been proven repeatedly. GEOmelt is a team of four engineering students that will attempt to blend these two technologies together in order to design a snowmelt system less reliant on fossil fuels.

As well as designing the snowmelt system for the Burton Street entrance, Team 13 will build a small size model that will demonstrate how the proposed geothermal snowmelt system would work. The model will include a concrete slab, a pump, piping, sensors, and a controller.

The Physical Plant at Calvin College currently uses several snowmelt systems near the entrances of many buildings around campus. The feasibility of installing a snowmelt system at the Burton St. Entrance to Calvin is of interest to the Physical Plant, due to the high traffic volumes and the snowplowing difficulties of the entrance.

Through preliminary research and analysis, it was found that a geothermally powered snowmelt system would be possible for the entrance. GEOmelt will continue to analyze the effectiveness of two geothermal snowmelt systems for this specific application using empirical data, theoretical calculations, and design.
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1. The Team

**Eric Geerlings** is from Grand Rapids, Michigan and will be graduating with a Bachelor of Science in Engineering with a Civil/Environmental concentration. He delayed graduation by one year in order to pursue a Business minor, Resident Assistant experiences, and ASCE Student Chapter leadership. For the past two summers, Eric has interned with Moore & Bruggink Inc. doing construction inspection. In his free time, Eric enjoys golfing and road-biking.

**Eric Ledy** grew up in Perry, Michigan, going to school and playing sports. He will be graduating from Calvin with a Bachelor of Science in Engineering with a Mechanical concentration. He has enjoyed the growth and challenges provided by a Christian atmosphere at Calvin. Furthermore, Calvin provided Eric with the opportunity to intern with Airbus in Bremen, Germany. During his final year, Eric will continue to be involved in the activities he enjoys, including working out, playing the guitar, and reading about technology and society.
Caleb Rottman is a senior Electrical Engineering student from Fargo, ND. This past summer he worked as an intern at GE Aviation in Grand Rapids. At Calvin, he is entering his fourth year as a member of the Varsity Track and Field team. He has minors in Mathematics and Biochemistry and is planning on pursuing his PhD in Biomedical Engineering after he graduates.

Jacob Speelman is from Calgary, Alberta and will be graduating with a Bachelors of Science in Engineering with a Mechanical Concentration. In addition to the engineering, he will graduate with a major in Philosophy and a minor in Archaeology. Jacob is currently employed as a research assistant in Calvin’s archaeology lab creating a Three-Dimensional virtual replica of the ruins at Umm el-Jimal, Jordan. In his free time, Jacob loves to hike, ski, work with wood, and read novels. He is also heavily involved with Calvin’s Middle East Club.
2. Introduction

2.1 Project Background

During the winter, the Burton Street entrance to Calvin College is kept free of snow and ice by plows and salting. However, it is still prone to snow and ice buildup during the winter, especially after city plows force snow from Burton Street onto the entrance, making it a dangerous area for students, faculty and staff. To prevent the buildup of snow, the Physical Plant of Calvin College must plow part of the intersection, and even the short stretch of Burton St. to the East of the entrance. These plowing and salting practices are possible during the early morning hours, but they are time consuming and dangerous at any other time. Thus, the Calvin College Physical Plant has expressed interest in examining the feasibility of an automatic snowmelt system.

Currently, the Physical Plant runs several snowmelt systems on Calvin’s campus to prevent the buildup of snow and ice in high traffic areas. These snowmelt systems are used at the entrances to many of the buildings including the Chapel, Devos Communications Center, the Spoelhof Fieldhouse Complex, as well as many of the dormitories. However, installing a snowmelt system at the Burton Street entrance presents a unique challenge that has never been addressed on campus before. The entrance is much farther away from buildings than other snowmelt systems on campus. This problem can be overcome in two different ways. Either more pipes will need to be installed to carry heat from existing boilers, or some sort of new snowmelt heating system will have to be installed.

Geothermal energy is an easily accessible energy source that might provide a cost effective solution to the unique snowmelt needs of the Burton Street entrance. This project incorporates
the mutual interest of the team members in geothermal technology with a genuine need to improve Calvin’s campus.

3. Problem Statement

3.1 Current State and Safety Concern of Burton Street Entrance

The current snow removal is done by a combination of plowing and salting, but the high level of traffic at the intersection makes this process very difficult during the day. Relying solely on physical labor does not provide the immediate and continual results that a snowmelt system does. If snow and ice is allowed to build up, people will slip and fall, and cars will be more likely to crash into each other or hit pedestrians. Implementing a snowmelt system at the Burton Street entrance would increase the safety of pedestrians as well as motorists by the removing snow and ice that make the entrance hazardous.

3.2 Environmental Factors

Inherently, our design is intimately linked to environmental factors. The very purpose of designing a snowmelt system at the Burton Street entrance is to control some of the potentially detrimental effects of a naturally occurring phenomenon: snowfall. Environmental factors include temperature, rate of snowfall, humidity, wind speed, and the density and porosity of the snow. Furthermore, the amount of annual snowfall that collects over the winter must be large enough to justify the capital investment that a snowmelt system requires.

Another environmental factor is the efficient use of energy. One of the main reasons for pursuing a geothermal solution to the snowmelt problem stems from its efficient use of energy.
According to the Environmental Protection Agency, geothermal systems are one of the most efficient heating systems available.\(^1\) For every unit of electrical energy put into the system, three to four units of heat can be extracted. The goal of this project is to transfer that potential efficiency into the design of a snowmelt system.

Furthermore, we have a responsibility in our design to ensure that harmful chemicals do not enter the environment. Snowmelt systems often contain anti-freeze chemicals, and these chemicals may potentially leak into the water table that is used by nearby wells to irrigate and provide potable water. First and foremost, this means designing a system that is leak-proof, but this also requires using additives in our system that will not be harmful in the case of leakage.

While potentially causing harm to the environment, snowmelt systems eliminate the need for de-icing chemicals. This is one of the positive environmental effects of using a snowmelt system.

### 3.3 Difficulties of Implementing Standard Snowmelt System

Designing a snowmelt system for the Burton Street entrance has its own unique challenges that set it apart from other locations. Its location presents two challenges. First of all, most snowmelt systems are installed near buildings, which facilitates easy hook-up to the existing boiler systems. Since the snowmelt system will not be next to a building, connecting to boilers will be more difficult. The second challenge is that the City of Grand Rapids owns the right-of-way on Burton St, and this means that Calvin would have to obtain encroachment permits before installing any snowmelt system in the right-of-way.

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3.4 Efficiency of Existing Snowmelt Options

There are many snowmelt systems around campus that the team intends to study during the upcoming winter. If possible, data will be gathered and other experiments will be conducted on one or two of these existing systems. Assuming these experiments yield reasonably good data, an approximate estimate of efficiency will be found. By studying the current systems, the team hopes to identify inefficiencies that can be improved by using geothermal energy.

3.5 Geothermal Systems Defined

A system using geothermal energy takes heat from the ground and moves it to where the heat is more useful, in this case, to the pavement to melt snow. For this system, there are two loops of pipe: one in the ground, and one in the pavement. Some systems use a Ground Source Heat Pump between these two loops of pipe. If this is the case, the GSHP (similar to a refrigeration system) increases the temperature of the heat taken from the ground. The higher temperature fluid is then pumped through the pavement loop. GSHPs operate as a refrigeration cycle would, which requires a refrigerant loop between the ground and pavement loops. To operate the compressor used in a GSHP, electricity is required.

If no Ground Source Heat Pump (GSHP) is used, the circulating fluid goes directly from the ground loop to the pavement loop. Without the increase of temperature from a GSHP, the cooler fluid will require a larger pump in order to achieve the same heat transfer rates. The design process will determine which of these two geothermal methods should be used.
4. Requirements

4.1 Rate of Melting

The melting requirements for snowmelt systems vary with respect to application. Some have classified snowmelt systems as being Type I, Type II, and Type III\(^2\). Type I allows for snow and ice to build up occasionally during peak demands, and eventually melt all of the snow. This is normally used for residential systems. Type II systems require that the pavement remain free of snow and ice at all times, but the surface may still remain wet. This is normally used for commercial applications. Type III systems require not only snow and ice free pavement, but that the pavement remain dry as well. These systems are only in critical in areas such as hospital emergency entrances, toll booths, and shipping areas.

The physical plant requires that there is no buildup of snow or ice, making the Burton St. Entrance snowmelt system a Type II system. Typical heat loads for a Type II system are 120-250 BTU/ft\(^2\). A complete analysis of Grand Rapids weather conditions, and ASHRAE snowmelt load requirements, will be necessary to determine the capacity needed for our system. The typical Type II system heat requirements will provide a way to check the reasonability of the results.

4.2 Maintenance

In general, geothermal systems are known to require very little maintenance. Nonetheless, geothermal systems, and especially snowmelt systems, must be designed with

maintenance in mind. If correct maintenance is not planned out and implemented, costly problems will arise.

4.2.1 Heat Source Piping

The geothermal exchange loops that are used to collect energy for the system are not expected to require maintenance at any time during their 50-100 year life, assuming they have been designed and installed correctly. Upon installation, these underground loops should be pressure tested to ensure no leaks are present in the system. After the piping is covered over, repairs of leaks in the system will likely require extensive excavation to pinpoint leaks.

4.2.2 Ground Source Heat Pump

Although the GSHP itself has few moving parts and is generally expected to operate for 20-30 years without significant maintenance, it is nonetheless desirable to design the system in such a way that adjustments and repairs can be made at a low cost. Accessibility is one of the largest maintenance issues in designing the heat pump. The two circulating pumps for the heat collecting and heat distributing loops, as well as the compressor, the heat exchangers, and the valves, should be oriented in such a way that they can be repaired, adjusted, or replaced with reasonably little effort. Over time, the bearings on the compressor and pumps may need to be re-greased or replaced if they are operating at decreased efficiency. The refrigerant may also require replacement after several years of use if it has deteriorated. Fortunately, general maintenance of

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heat pumps do not typically require special skills. Therefore implementing a snowmelt system that uses GSHPs will not introduce technologies that the Physical Plant cannot handle.

4.2.3 Maintaining Efficiency

The efficiency of heat exchangers diminishes as the fouling factors increase. To maintain high efficiencies, certain flushing processes may be required periodically. Any system that is designed will have to take these fouling factors into consideration when deciding which fluid or pipe to use. The benefit of higher efficiency will have to be weighed against the cost and difficulty of maintenance. The energy transfer efficiency could be monitored by measuring the temperature of the fluid at different points in the system, as well as the flow rates of these streams. Comparing these values over time can show whether or not maintenance is required.

4.3 Heat Source Tubing

Every geothermal system requires a series of pipes to absorb the energy within the earth and supply the energy either directly to the pavement or to the heat pump via a circulating fluid. Several different types of pipe materials and configurations are available to complete this task, but generally, the current industry standard recommends using high density polyethylene (HDPE) piping. HDPE has a number of characteristics that make it particularly well-suited to the task.

For instance, the flexibility of HDPE, its relatively light weight, and its impact resistance significantly improve the ease of installation of the geothermal system, thus decreasing the cost. First, the flexibility of HDPE pipe allows it to be bent to the desired shape by hand without the need for pipe-bending equipment or additional fittings, which take time and money to install. Second, compared to metal piping of comparable diameter and pressure capacity, HDPE is much
lighter and can therefore be installed in significantly longer lengths with less effort involved.

Third, due to its impact resistance, HDPE pipe is well-suited to cold-weather installation when low temperatures make the working materials more brittle. This is an important consideration when backfilling, when sharp rocks may strike the pipe as it is being covered.

Various other properties make HDPE well-suited for extending the life span and long-term functionality of the geothermal pipe system. For instance, HDPE pipe has a high fatigue strength; according to the Handbook of Polyethylene Pipe, “[Polyethylene pipe] can withstand multiple surge pressure events up to 100% above its maximum operating pressure without any negative effect to its long-term performance capability.”

In addition, unlike many metallic pipes, HDPE is not prone to rusting or any other electrochemical processes of decay and it resists the growth of organic materials. Polyethylene pipe—categorized as “smooth pipe,” the category that gives the “lowest resistance to fluid flow”—is very hydraulically efficient. Because of its resistance to corrosion and organic growth, HDPE maintains this efficiency over years of use. In a geothermal application, where efficiency is of paramount importance and where the energy requirements of the fluid-circulating pumps make up a significant portion of the total energy expenditure, hydraulically efficient pipes are a necessity. Thanks to the physical and chemical properties discussed, “the PE pipe industry estimates a service life for PE pipe to be,


conservatively, 50-100 years provided that the system has been properly designed, installed and operated in accordance with industry established practice and the manufacturer’s recommendations.”

Although the relatively low thermal conductivity of plastic seems to prohibit its use where rapid heat transfer is desired, for various reasons, it remains a viable choice. High density polyethylene is classified as an insulator with a thermal conductivity value of 0.42-0.51 W/mK at a temperature of 25°C. Because the purpose of the heat exchange pipes is to transfer heat from the earth into the circulating fluid, a higher thermal conductivity value is preferable to a lower. Consider the following values for thermal conductivity:

<table>
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<tr>
<th>Material</th>
<th>Thermal Conductivity, K (W/mK) @25°C</th>
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<tbody>
<tr>
<td>Aluminum</td>
<td>250</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>54</td>
</tr>
<tr>
<td>Copper</td>
<td>401</td>
</tr>
<tr>
<td>High Density Polyethylene (HDPE)</td>
<td>0.42-0.51</td>
</tr>
<tr>
<td>Polyvinyl Chloride (PVC)</td>
<td>0.19</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>16</td>
</tr>
</tbody>
</table>

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Although HDPE has a higher thermal conductivity than PVC, clearly, several other potential pipe materials would do a significantly better job of transferring heat from the ground to the circulating solution. However, there are a few factors that play into the equation to make HDPE a viable pipe material, despite its low thermal conductivity.

First, the transfer of energy from the ground to the fluid is limited not only by the thermal conductivity of pipe itself, but also by other factors, including the ability to transfer heat from the inner pipe wall to the circulating fluid—reflected by the heat transfer coefficient due to convection—as well as the ability to transfer heat from the surrounding soil to the outer pipe wall.

Second, the transfer of heat from the ground to the geothermal system is limited by the rate at which the soil surrounding the pipes can receive heat from its own surroundings. If heat is transferred away from the surrounding soil by the pipes at a rate faster than the soil can regain heat from its own surroundings, the earth immediately around the pipes will be cooled until it reaches a state of equilibrium. In this case, the rate of heat exchange between the pipes and the soil would be limited more by the thermal conductivity of the soil itself than that of the pipe material, and the thermal conductivity of soil is relatively low compared to the metals listed in Table 1—around 1.5W/mK for dry earth, although this varies widely by soil constitution and moisture.

Third, although the alternatives with higher thermal conductivities may still seem preferable in light of the aforementioned considerations, HDPE pipe has a number of benefits, several of which have already been discussed, that outweigh this downside.

Certain cost considerations also play into the choice of pipe material. For instance, although copper may initially seem to be a viable option, as it is reasonably corrosion resistant
and has a very high thermal conductivity, it is prohibitively expensive at nearly $3.00/lb.$^9$ On the contrary, HDPE pipe costs relatively little compared to alternatives of similar diameter and pressure capacity. This means a lower initial investment and a decreased period of time before the investment pays for itself relative to alternatives.

4.3.4 Pipe Configurations

4.3.4.1 Open Loop

Open loop systems receive a supply of ground water, usually from a well. After the much of the energy in the ground water is transferred to the heat pump using a heat exchanger, the water is discharged. Because the water is being continually replenished and is discharged back into the environment, no additives are used to prevent freezing. This means that the pump may never be shut off. Allowing ice to form inside the pipes could lead to bursting. It should also be noted that the water must be discharged in environmentally acceptable and legal ways. For instance, The Department of Environmental Quality does not allow “surface water” to be injected back into a well, and there are also restrictions on how city storm sewers may be are used for drainage.

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Closed loop systems circulate the same solution repeatedly to absorb energy from the earth. Typically, closed loop systems use some type of additive (often antifreeze) to prevent freezing. There are a variety of unique configurations for closed loop systems shown below.

Pond systems are a further subset of closed loop systems. Geothermal piping is laid at the bottom of a pond to absorb geothermal heat.
Vertical systems are another option for closed loop configurations. Loops of pipe are lowered into vertical bore holes, usually between 50-400 feet deep.

![Figure 3: Closed Loop Vertical Heat Exchanger](image)

Horizontal is yet another type of closed loop configuration. Piping is laid at the bottom of trenches which are then backfilled. The pipes are typically laid either in long loops that lie parallel to each other or in a series of coils. The coiled method is more common for HDPE pipes.

![Figure 4: Closed Loop Horizontal Heat Exchanger Pipe Configurations](image)

### 4.4 Heat Dissipating Pipes

Many of the design considerations that make polyethylene pipe well suited for use as a ground-source heat exchanger also make it reasonably well suited to serve as the in-slab heating element which transfers heat from the heat pump to the concrete. However, cross-linked polyethylene (PEX) is better suited to this application than the High Density Polyethylene
(HDPE) that will be used for the geothermal loop, primarily because of its higher performance at
higher and lower temperatures.

According the Handbook of PE Pipe, “PE pipe’s typical operating temperature range is
from [-17.8°C] to [60°C] for pressure service.”\footnote{Second Edition Handbook of PE Pipe, Copyright 2009 Plastic Pipe Institute,
[http://www.plasticpipe.org/publications/pe_handbook.html]} Unfortunately, the upper range of use for PE
pipe is close to the operating temperature for our heating pipes. PEX piping on the other hand is
approved for use up to 93°C, and also performs better at lower temperatures than PE.\footnote{http://www.ppfahome.org/pex/faqpex.html Plastic Pipes and Fittings Association, n.d. Web. 16
Nov. 2009.} This improved performance over a larger range of temperatures is very important for snowmelt
purposes. The heating pipe is exposed to both higher and lower temperatures than the geothermal
ground loops: higher because the fluid that is pumped through it enters at a higher temperature
(50-60°C); lower because, while the snowmelt system is not in operation, the temperature of the
slab may drop well below 0°C.

The cross-linking in PEX improves its tensile strength, impact resistance, and resistance
to brittle fracture. These improvements help to explain the pipe’s increased durability, especially
at low temperatures when brittle fracture is particularly likely.\footnote{http://www.pexsupply.com/resources/pexPlumbing PEX Supply.com, n.d. Web. 10 Nov. 2009.} Because the concrete slabs in
which the heating pipes are contained are subject to low temperatures, often well below 0°C,
there is always a danger of having the solution inside the pipes freeze while the system is not in

\footnote{Second Edition Handbook of PE Pipe, Copyright 2009 Plastic Pipe Institute,
[http://www.plasticpipe.org/publications/pe_handbook.html]}

Nov. 2009.}

operation. With metal pipes like copper, this freezing could cause the pipes to burst. Plastic pipes, however, because of their flexibility may allow for significantly greater expansion of the pipes without bursting. This danger can also be significantly decreased with the use of additives, such as antifreeze or alcohol, which prevent the freezing of the solution.

PEX is classified as an insulator, with a thermal conductivity similar to that of HDPE. Once again, therefore, it may initially seem to be a poor choice for a snowmelt system, in which the rapid transfer of heat away from the circulating fluid is desirable. However, it can be shown that the transfer of heat from the fluid to the surface of the concrete is limited significantly more by the thermal conductivity of the concrete itself than it is by the thermal conductivity of the piping. Therefore, in light of PEX piping’s other advantageous characteristics, the benefits can be seen to outweigh this downside. This can be shown briefly using a highly simplified calculation in which the transmission of heat from the pipe to the surface above the pipe is approximated as conduction through two parallel plates, neglecting the heat transfer due to convection and neglecting the actual geometry of the system.

Consider two cases that mimic real alternatives, one in which a ¾” copper pipe of thickness $t_{copper} = 1.6\text{mm}$ is used, and one in which a ¾” PEX pipe of thickness $t_{PEX} = 2.4\text{mm}$ is used. The thickness of the concrete above the pipes is 40mm, mimicking a standard pipe depth for snowmelt systems.\(^3\) The thermal conductivity of the copper is $k_{copper} = 401\text{W/mK}$; for PEX it is $k_{PEX} = 0.41\text{W/mK}$; for the concrete it is $k_{concrete} = 0.8\text{W/mK}$. Assume a temperature of $T_i = 55^\circ\text{C}$ at the inside of the pipe wall and the temperature at the outside surface of the concrete is $T_o = -5^\circ\text{C}$.
Using the following equation to approximate the heat transfer per unit area through the pipe wall and concrete layer:

\[
\frac{Q}{A} = \frac{(T_1 - T_0)}{(t_{\text{pipe}}/k_{\text{pipe}} + t_{\text{concrete}}/k_{\text{concrete}})}
\]

We find for the copper pipe:

\[
\frac{Q}{A} = \frac{55-(-5)}{0.0016/0.040 + 0.41/0.80} = 1200 \text{W/m}^2
\]

And for the PEX pipe:

\[
\frac{Q}{A} = \frac{55-(-5)}{0.0024/0.040 + 0.41/0.80} = 1070 \text{W/m}^2
\]

Thus, we can see that although the thermal conductivity of the PEX pipe is significantly lower than that of the copper pipe, the total heat transfer through the concrete slab is comparable for each alternative due to the relatively low thermal conductivity of the concrete itself.

4.5 Control System

Snowmelt systems are controlled either manually or automatically. With manual control, a switch is flipped by an operator. This control method has several disadvantages. First, it is necessary to have someone always be in charge of running the system. Second, a manual operator may not have time to react when it begins to snow. Third, if left unattended, the system will remain on, wasting money as well as energy.
Automatic systems have a controller that operates using some, if not all, of the following sensors:

4.5.1 Outdoor Thermostat

The temperature outside will determine whether or not the system will be in the range of temperatures where it is useful to operate. If the temperature is above freezing, the system will not turn on, because it is presumed that snow will not form. If the temperature is too low, the system will also not run because it would make the area more dangerous by not effectively melting enough snow. Any temperature between these two extremes and the system will be in either a running mode or a standby mode.

4.5.1 Pipe Thermocouples

Pipe thermocouples will monitor temperatures at various points in the pipes (usually just the liquid flowing in and out of the pavement). This will ensure that the concrete slab is not heated too quickly, which would result in thermal shock for the concrete, causing it to crack.

4.5.2 Snow/Moisture Detectors

A moisture detector is implemented either in the concrete or outside of the system. When snow falls, the sensor will detect moisture. At this point, if the system is in idle mode, the system will switch to being on.

4.6 Run-off Control

After the snow has melted, the water must drain off the pavement in such a way that it will not refreeze on an adjacent surface. This means that additional catch basins or a separate collection system may need to be included in our final design for the Burton St. Entrance. One
possible drainage option is a trench grate. In Figure 5 below, a few of the various trench grate offerings from East Jordan Iron Works (EJIW) are shown.  

![Trench Grate Designs](image)

**Figure 5: Two EJIW Trench Grate Designs**

EJIW produces custom clear-span grates that are suitable for various applications. The grates are certified for general traffic service and AASHTO H-20 loading conditions. This means that if grates were installed to handle snowmelt runoff at the Burton St. Entrance, cars and trucks would not damage the grates. Figure 6 shows a profile view of an EJIW trench grate.

![Profile View of Trench Grate](image)

**Figure 6: Profile View of an EJIW Trench Grate**

---

5. Design Context

5.1 Climate/Weather Patterns

In order to properly design a snowmelt system, a careful study of the local climate must be conducted. As seen in Figure 7 below, different locations have different heating demands. According to the ASHRAE Handbook of HVAC Applications, the heat required for melting snow depends on five atmospheric factors: (1) rate of snowfall, (2) air dry-bulb temperature, (3) humidity, (4) wind speed, and (5) apparent sky temperature.\(^\text{14}\)

---

The average annual snowfall in Grand Rapids is 71.6 inches.\(^{15}\) However, knowledge of the annual average snowfall is not sufficient when designing a snowmelt system. As was noted earlier, the rate of snowfall is much more important for design. In Grand Rapids, the rate of snowfall is often affected by what meteorologists call “lake-effect snow.” This phenomenon occurs when cold air picks up water vapor as it crosses a large body of warm water. Lake-effect snow yields snowfall rates as high as 6 inches per hour.\(^{16}\) Rather than guessing at what these peak snowfall rates might be, or how often they occur, comparisons are made between the weather data in Grand Rapids and two other cities with similar weather conditions that have more available data. These two cities are Buffalo, New York, and Portland, Maine. Portland is similar to Grand Rapids in terms of annual snowfall, average temperatures, and wind speed. However, Portland does not experience strong lake-effect snowstorms like Grand Rapids. Buffalo on the other hand, because of its proximity to Lake Erie, is subject to lake-effect snowstorms.


In Table 2 and Table 3 below, a summary of relevant weather data from each city is given.

Table 2: Average Monthly Snowfall

<table>
<thead>
<tr>
<th>Average Snowfall (Inches)</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>Grand Rapids Michigan</th>
<th>Grand Rapids vs. Buffalo</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>19</td>
<td>23.3</td>
<td>20.2</td>
<td>87%</td>
</tr>
<tr>
<td>February</td>
<td>17.4</td>
<td>18.2</td>
<td>11.9</td>
<td>85%</td>
</tr>
<tr>
<td>March</td>
<td>13</td>
<td>11.7</td>
<td>10</td>
<td>97%</td>
</tr>
<tr>
<td>April</td>
<td>3.1</td>
<td>3.1</td>
<td>3</td>
<td>233%</td>
</tr>
<tr>
<td>May</td>
<td>0.2</td>
<td>0.3</td>
<td>0</td>
<td>80%</td>
</tr>
<tr>
<td>October</td>
<td>0.2</td>
<td>0.3</td>
<td>0.7</td>
<td>67%</td>
</tr>
<tr>
<td>November</td>
<td>3</td>
<td>11.5</td>
<td>7.7</td>
<td>89%</td>
</tr>
<tr>
<td>December</td>
<td>14.6</td>
<td>22.7</td>
<td>18.1</td>
<td>89%</td>
</tr>
</tbody>
</table>

| Annual Snowfall Total     | 70.5           | 91.1              | 71.6                  | 89%                      |

Notice how similar monthly snowfall measurements\(^{17}\), average high and low temperatures\(^{18}\), humidity\(^{19}\), and wind speeds\(^{20}\) are for these three cities. Thus, Grand Rapids should have ASHRAE snowmelt system heat load requirements that are somewhere in between the values given above in Figure 7 for Buffalo and Portland.


In addition, Table 4 shows relevant weather data for all three cities. Full month by month averages for wind speed and humidity can be seen in Appendix 1 and 2. Appendix 1 also shows a table displaying heat output and mean fluid temperature for hydronic snow-melting systems and how that varies based on wind speed and rate of snowfall.

### Table 3: Average Monthly High and Low Temperatures

<table>
<thead>
<tr>
<th>Average High Temperature (°F)</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>Grand Rapids Michigan</th>
<th>Grand Rapids vs. Buffalo</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>31</td>
<td>31</td>
<td>29</td>
<td>-2</td>
</tr>
<tr>
<td>February</td>
<td>34</td>
<td>33</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>March</td>
<td>42</td>
<td>42</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>April</td>
<td>53</td>
<td>54</td>
<td>57</td>
<td>3</td>
</tr>
<tr>
<td>May</td>
<td>63</td>
<td>66</td>
<td>70</td>
<td>4</td>
</tr>
<tr>
<td>October</td>
<td>58</td>
<td>59</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>November</td>
<td>47</td>
<td>47</td>
<td>46</td>
<td>-1</td>
</tr>
<tr>
<td>December</td>
<td>36</td>
<td>36</td>
<td>34</td>
<td>-2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Low Temperature (°F)</th>
<th>Portland</th>
<th>Buffalo</th>
<th>Grand Rapids</th>
<th>GR vs. Buffalo</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>12</td>
<td>18</td>
<td>16</td>
<td>-2</td>
</tr>
<tr>
<td>February</td>
<td>16</td>
<td>19</td>
<td>18</td>
<td>-1</td>
</tr>
<tr>
<td>March</td>
<td>25</td>
<td>26</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>35</td>
<td>36</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>44</td>
<td>48</td>
<td>47</td>
<td>-1</td>
</tr>
<tr>
<td>October</td>
<td>37</td>
<td>43</td>
<td>40</td>
<td>-3</td>
</tr>
<tr>
<td>November</td>
<td>30</td>
<td>34</td>
<td>31</td>
<td>-3</td>
</tr>
<tr>
<td>December</td>
<td>19</td>
<td>24</td>
<td>21</td>
<td>-3</td>
</tr>
</tbody>
</table>

Table 5 below shows detailed system requirements for snowmelt systems in Portland Maine and Buffalo New York. The far right column is a rough estimate of how much heat a Grand Rapids snowmelt system will need to produce.

### Table 4: Average Wintertime Humidity and Annual Average Wind Speed

<table>
<thead>
<tr>
<th>Humidity (%) Wind Speed (MPH)</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>Grand Rapids Michigan</th>
<th>Grand Rapids vs. Buffalo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Winter Morning Humidity</td>
<td>76.75</td>
<td>78.38</td>
<td>81.25</td>
<td>2.88</td>
</tr>
<tr>
<td>Average Winter Afternoon Humidity</td>
<td>58.00</td>
<td>64.50</td>
<td>64.25</td>
<td>-0.25</td>
</tr>
<tr>
<td>Annual Average Windspeed</td>
<td>8.7</td>
<td>11.8</td>
<td>9.8</td>
<td>-2.06</td>
</tr>
</tbody>
</table>
The interpolated numbers for Grand Rapids were found by using a weighted average of the Portland and Buffalo data. Because of the similarity between Buffalo and Grand Rapids caused by lake-effect snow patterns, the Buffalo data was given 3 times the weight of the Portland data. One major for this project is to determine whether this estimate for a Grand Rapids snowmelt system is reasonable or not.

### 5.2 Earth Temperature Constraints

Ground temperature fluctuates from season to season, as can be seen below in Figure 8. According to the figure, ground temperature varies approximately 20 degrees throughout the course of a year at a depth of 5 feet. At a depth of 30 feet, the temperature is constant. In

---

**Table 5: Snow-Melting System Requirement Interpolation for Grand Rapids**

<table>
<thead>
<tr>
<th>Snow-Melting Loads (Btu/h-ft²)</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required to Provide a Snow-Free Area Ratio of 1.0 for 99% of the Time</td>
<td>266</td>
<td>330</td>
<td>314</td>
<td>314</td>
</tr>
<tr>
<td>Required to Provide a Snow-Free Area Ratio of 0 for 99% of the Time</td>
<td>152</td>
<td>112</td>
<td>122</td>
<td>122</td>
</tr>
</tbody>
</table>

**Annual Operating Data**

<table>
<thead>
<tr>
<th></th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Melting, (h/yr)</td>
<td>157</td>
<td>292</td>
<td>258.3</td>
<td>258</td>
</tr>
<tr>
<td>Time Idling, (h/yr)</td>
<td>1996</td>
<td>1779</td>
<td>1833.3</td>
<td>1833.3</td>
</tr>
<tr>
<td>2% Min. Snow Temp., °F</td>
<td>7.3</td>
<td>3.8</td>
<td>4.7</td>
<td>4.7</td>
</tr>
</tbody>
</table>

**Annual Heat Flux Requirement (Btu/ft²)**

<table>
<thead>
<tr>
<th>System Designed for Melting, A_r = 1</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>13,318</td>
<td>23,929</td>
<td>21,276</td>
<td>21,276</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Designed for Melting, A_r = 0.5</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,819</td>
<td>14,735</td>
<td>13,294</td>
<td>13,294</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Designed for Idling, A_r = 1</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>115,248</td>
<td>105,839</td>
<td>108,191</td>
<td>108,191</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Designed for Idling, A_r = 0.5</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>115,196</td>
<td>105,521</td>
<td>107,940</td>
<td>107,940</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Designed for Idling, A_r = 0</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>75% Weighted Toward Buffalo #</th>
<th>Interpolation for Grand Rapids</th>
</tr>
</thead>
<tbody>
<tr>
<td>114,836</td>
<td>101,945</td>
<td>105,160</td>
<td>105,160</td>
<td></td>
</tr>
</tbody>
</table>
western Michigan this constant ground temperature is 49° F, on average.\textsuperscript{21} In order to fully understand the changes in ground temperature during the winter, the team will be installing four thermocouples near the Burton St Entrance, at depths of 2, 4, 6, and 8 feet. Temperature data will be gathered weekly and plotted relative to depth. Through this winter-long experiment, the team will determine what temperatures can be expected for a horizontal closed-loop pipe setup in that location. This will be a deciding factor in determining the feasibility of a geothermal snowmelt system.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{annual_ground_temperature_swing.png}
\caption{Annual Ground Temperature Swing\textsuperscript{22}}
\end{figure}


5.3 Water Well Availability

There are seven wells on Calvin College’s campus, and one of these wells is located near the Burton St. Entrance. Initially, the team thought that an open loop system using well water might be a viable option for getting ground temperature water for the geothermal system. However, the team later discovered that the Department of Environmental Quality is very concerned about ground water contamination. Therefore, the option of using an open loop system was eliminated.

5.4 Design Norms

Calvin College is a distinctively Christian, academically excellent liberal arts college that shapes minds for intentional participation in the renewal of all things.23 As engineering students here at Calvin College, we have chosen to focus on the design norms of caring and stewardship.

5.4.1 Caring

In this project, a great deal of effort will be put toward caring for individuals who will be affected by the snowmelt system. This is why a main concern is for the safety of the users. This safety applies to pedestrians, vehicles, and snow plows. A snowmelt system will provide traction for pedestrians and vehicles, reducing pedestrian falls, vehicle-pedestrian collisions, and vehicle-vehicle collisions.

5.4.2 Stewardship

Concern for the environment is a major reason for this project, and this includes responsible energy use. We believe that current snowmelt systems use an unnecessary amount of fossil fuels in order to melt snow. If geothermal energy can increase the efficiency of snowmelt systems while remaining cost effective, we believe that this technology should be used.

6. Alternative Designs

There are many ways to remove snow from places where it is undesirable. There are strengths and weaknesses that come with each method and it will take a thorough analysis to determine which system is best for the given situation. Currently, there are three main ways of removing snow, with some sub-categories within the main three groups. Both manual and automatic removal is possible, with two categories of automatic removal. The possible automatic removal methods are electric melting and hydronic melting.

6.1 Manual Systems

Most well known, perhaps, manual snow removal can be done with a shovel or plow. Physical removal of the snow is often followed by the use of chemicals, such as salt, to prevent ice buildup.

6.2 Electric Systems

There are two main types of electric snowmelt systems, the buried cable system, and the skin-effect system. With the buried cable system, the electric heating element is installed
directly in the concrete, and this is used to melt the snow. In the skin-effect system, wires are installed in the concrete, but also tubes with cables in them are installed near the surface. This method works on electric induction where the current going through the wires heats the conductive cables due to the electromagnetic flux.

6.3 Hydronic Systems

This method melts snow by passing a heated fluid, usually water and propylene glycol, but sometimes steam, through pipes buried in the concrete. There can be many heat sources used to reheat the fluid as it circulates through the snow melt system. The source of this heat may make a large difference in the cost to operate the system. Heat sources could be boilers that use propane, natural gas, oil, or electricity, wood burners, solar heat collection devices, and geothermal heating systems. In the case of a steam system, a power plant or other industrial plant may have available steam that could be used. This project focuses on using geothermal energy as the heat source, and will recommend which application of geothermal energy should be used.

One possible method for melting snow with geothermal heat is by using a single hydronic loop. In this case, circulating fluid is used to capture geothermal heat, as in any geothermal system. However, instead of using a heat pump to raise the temperature of fluid, it is piped directly through the concrete, which dissipates heat. This idea can be seen in Figure 9.

Figure 9: Geothermal Snowmelt using a Single Loop; No Heat Pump
Thus, the fluid entering the slab is approximately the same temperature as the ground from which it came (around 49°F). Alternatively, if it is desirable to separate the heat capturing loop from the heat dissipating loop, it is possible to do so with the addition of a heat exchanger between the two loops as in Figure 10. This would be done if it is desirable to have two separate fluids circulating through the system instead of the same fluid circulating through both the ground and the concrete. Using heat exchangers with no Ground Source Heat Pump will most likely not be utilized because heat exchangers are not 100% efficient at transferring heat, which means the fluid temperature going through the concrete slab would be even cooler than fluid used in one continuous loop. The advantage would be that the fluids could be optimized for each loop.

**Figure 10: Geothermal Snowmelt using Two Loops and a Heat Exchanger; No Heat Pump**

Generally, snowmelt systems operate at around 120-140°F. Therefore, it must be ensured that the relatively lower temperature fluid being circulated through the concrete is capable of keeping up with the snowfall requirements of the region. Assuming that it is capable, the system—which will necessarily require significantly longer loops in the concrete and possibly also in the ground—must prove to be of comparable cost to a heat pump. Furthermore, it must be ensured that the increased size or number of coils running through the concrete to account for the lower temperature must not undermine the strength of the concrete.
Figure 11: Geothermal System using Two Loops and a Heat Pump

As mentioned in section 3.5, a system using geothermal energy takes heat from the ground and moves it to where the heat is more useful. The Ground Source Heat Pump as a part of the geothermal system for a house can be seen in Figure 11: Geothermal System using Two Loops and a Heat Pump.

\[\text{Figure 11: Geothermal System using Two Loops and a Heat Pump}^{24}\]

\[\text{As mentioned in section 3.5, a system using geothermal energy takes heat from the ground and moves it to where the heat is more useful. The Ground Source Heat Pump as a part of the geothermal system for a house can be seen in Figure 11: Geothermal System using Two Loops and a Heat Pump.}\]


\[<\text{http://www.digtheheat.com/photos/heatpumpdiagram_full.jpg}>.\]
Loops and a Heat Pump. It would work in the same way for a snowmelt system, only the pavement would replace the house radiator as the heat sink.

7. Preliminary Design

7.1 Model

7.1.1 Control

The design for the controller is as follows:

First, a microcontroller is required to receive information regarding the system and then apply the given data in order to ensure that the system melts snow efficiently. The controller chosen is the Arduino™ Duemilanove. It was chosen for its low cost and ease of use, as well as the appropriate input/output pins and analog to digital converters.

![Arduino Duemilanove](http://www.arduino.cc/en/Main/ArduinoBoardDuemilanove)

Figure 12: Microcontroller: Arduino Duemilanove

---

Second, temperature sensors will be used to monitor the temperatures of the heated liquid entering the concrete slab, the cooled liquid leaving the slab, and the ambient air temperature. The sensors that measure the temperature of the liquid entering and leaving the slab will be used to ensure that the concrete is heated evenly. If there is too great a difference between the temperature of the pipe and the temperature of the concrete, the concrete may expand, reducing the lifespan of the system. The temperature sensor measuring the ambient temperature will ensure that the system is operating only when it is required. At relatively high ambient temperatures the snowmelt system would be unnecessary, and at very low temperatures, the snowmelt system must be shut off in order to ensure that it is not creating ice. A snow sensor will also be used to determine if the system should be running, assuming the ambient temperature is within the useful range of the system. An LCD display will be used to display the temperatures and the current status of the system. Finally, an interface will need to be designed so that the controller will interact with the mechanical systems of the model.

---

7.1.2 Heat Pump

The model built to simulate the Burton St. Entrance will have two main limitations, those being the cost and available space to build the model. The complexity of the model will be limited by cost, and the size of the model will be limited by the mobility required for the project. The model will consist of a loop of pipe through a simulated ground environment, a loop of pipe through a test concrete patch, and a pump to circulate the liquid. A controller will automatically control the operation of this system based on sensor inputs. Sensors will be bought and used for the inputs to the controller. Hopefully a heat-pump, similar to one used in a refrigerator, can be acquired and converted to work for the model application. In this case, the heat pump would interface with the ground loop and the concrete loop, moving heat from the ground loop into the concrete loop.

7.2 Large-scale System

A preliminary analysis has been done in EES to determine system specifications. The ASHRAE Handbook also describes snowmelt calculations and correlations which will serve to
improve and update the previously calculated system in EES. The results of the preliminary design using a heat pump are this: for snow to be melted at a rate of 0.8 in/hr, the heating fluid needs to be pumped at 66 gal/min at an entrance temperature of 104°F. This will supply energy at a rate of 100.5 kW to melt the snow. More data will be acquired in the following semester for the conditions of the system without the heat pump. See Appendices 5 and 6 for the detailed calculations.

7.2.1 Pump

The pump is a vital piece of equipment that keeps the fluid flowing and the snow melting. Properly sizing a pump is an important design decision to make to be sure there is adequate flow, but also to be sure that the pump is not oversized, resulting in wasted energy. As a general principle, when higher temperature fluids are circulating through the system, the fluid can be circulated slower. Thus, hotter fluids require smaller pumps. Conversely, with lower temperature fluid, a larger pump is needed so that the adequate amount of heat transfer can be achieved.

The preliminary analysis show that for a flow rate of 66 gal/min, a 1 HP pump will be required. For the solution without the heat pump, a much more powerful pump will be required. Further analysis will be required before choosing a final solution for the design.
8. Schedule

The rough schedule for the project is shown below in Table 6: Project Schedule. A visual representation of this schedule can be seen in Appendix 4, which is a complete Gantt Chart.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Resource Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPFS Rough Draft Due</td>
<td>1 day</td>
<td>Wed 11/10/09</td>
<td>Wed 11/10/09</td>
<td>All</td>
</tr>
<tr>
<td>Revised Website Posted</td>
<td>1 day</td>
<td>Wed 11/25/09</td>
<td>Wed 11/25/09</td>
<td>Caleb</td>
</tr>
<tr>
<td>Industrial Consultant Brief</td>
<td>1 day</td>
<td>Mon 11/30/09</td>
<td>Mon 11/30/09</td>
<td>All</td>
</tr>
<tr>
<td>Attain tools, pipe, and thermocouples</td>
<td>10 days</td>
<td>Tue 11/24/09</td>
<td>Mon 12/7/09</td>
<td>Jacob</td>
</tr>
<tr>
<td>Install Thermocouples</td>
<td>2 days</td>
<td>Mon 12/14/09</td>
<td>Tue 12/15/09</td>
<td>All</td>
</tr>
<tr>
<td>Thermocouple Weekly Data Gathering</td>
<td>78 days</td>
<td>Wed 12/16/09</td>
<td>Fri 4/2/10</td>
<td>All</td>
</tr>
<tr>
<td>2nd Oral Presentation</td>
<td>1 day</td>
<td>Mon 12/27/08</td>
<td>Mon 12/7/08</td>
<td>Jacob and Geerlings</td>
</tr>
<tr>
<td>PPFS Edit the Final Draft</td>
<td>7 days</td>
<td>Wed 12/2/09</td>
<td>Thu 12/10/09</td>
<td>All</td>
</tr>
<tr>
<td>PPFS Final Draft Due</td>
<td>1 day</td>
<td>Fri 12/11/09</td>
<td>Fri 12/11/09</td>
<td>All</td>
</tr>
<tr>
<td>Update the Website with PPFS etc.</td>
<td>2 days</td>
<td>Mon 12/14/09</td>
<td>Tue 12/15/09</td>
<td>Caleb</td>
</tr>
<tr>
<td>Interim Begins</td>
<td>1 day</td>
<td>Wed 1/6/10</td>
<td>Wed 1/6/10</td>
<td>All</td>
</tr>
<tr>
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<td>Thu 1/14/10</td>
<td>Geerlings</td>
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<td>Fri 1/8/10</td>
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</tr>
<tr>
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<tr>
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<td>5 days</td>
<td>Tue 1/26/10</td>
<td>Mon 2/1/10</td>
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<td>Mon 1/26/10</td>
<td>Tue 1/26/10</td>
<td>Geerlings and Ledy</td>
</tr>
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<td>9 days</td>
<td>Wed 1/27/10</td>
<td>Mon 2/9/10</td>
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</tr>
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<td>5 days</td>
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<td>Thu 2/4/10</td>
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</tr>
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<td>Caleb and Jacob</td>
</tr>
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<td>16 days</td>
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<td>Tue 3/9/10</td>
<td>Caleb and Jacob</td>
</tr>
<tr>
<td>Begin Building and Testing the Model</td>
<td>15 days</td>
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<td>Caleb and Jacob</td>
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<td>Fri 3/6/10</td>
<td>Geerlings</td>
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<td>Wed 4/14/10</td>
<td>Geerlings</td>
</tr>
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<td>Wed 4/14/10</td>
<td>Ledy</td>
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<td>1 day</td>
<td>Mon 4/12/10</td>
<td>Mon 4/12/10</td>
<td>Geerlings</td>
</tr>
<tr>
<td>Complete Final Written Report</td>
<td>16 days</td>
<td>Tue 4/13/10</td>
<td>Mon 5/3/10</td>
<td>All</td>
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<td>13 days</td>
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<td>Fri 4/30/10</td>
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<td>Create Final Posters</td>
<td>5 days</td>
<td>Wed 4/28/10</td>
<td>Tue 5/4/10</td>
<td>All</td>
</tr>
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<td>Create Final Presentation Powerpoint</td>
<td>7 days</td>
<td>Wed 4/28/10</td>
<td>Thu 5/6/10</td>
<td>All</td>
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<td><strong>PROJECT NIGHT</strong></td>
<td>1 day</td>
<td>Sat 3/8/10</td>
<td>Sat 3/8/10</td>
<td>All</td>
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</table>
9. Feasibility

9.1 Design

Initial analysis suggests that the design of a snowmelt system for Burton St. Entrance is feasible. Snowmelt systems using geothermal heat have been implemented around the world. Also, there are numerous resources for the design of traditional snowmelt systems. These resources, as well as data specific to Calvin College, will allow for a suitable analysis of the specific location and installation of the snowmelt system. The ASHRAE handbook provides the necessary equations and correlations that are used in calculating snowmelt requirements.

Some difficulty in the design has been encountered in finding accurate and relevant data for Grand Rapids required by ASHRAE formulas. However, a direct correspondence with the Calvin College Physical Plant will offer invaluable insight into the success and failures of current snowmelt systems on campus. Current standards in use on campus will be the starting point for the design.

9.2 Model

A small-scale model will be built to demonstrate the operation of a geothermal snowmelt system. The model will not contain a heat pump, due to the expense of its implementation as well as the lack of team resources to work with refrigerants. However, to simulate the warmer ground temperatures, heating coils may be installed around the ground pipes of the model. The largest obstacle to the building of this model is the cost of the parts, and many of the parts are hoped to be donated.
9.3 Cost of Implementation

The cost of installing and operating a geothermal snowmelt system at the Burton St. Entrance will be a large factor in the decision for actual implementation by Calvin College. Currently, snow is removed by plows and de-icing chemicals. Given the length of road that needs to be plowed, the marginal cost of plowing Burton St. is very small. However, comparing the geothermal system with the next best automatic snow removal system will give a good competitive comparison. Whether or not the investment is worthwhile will ultimately need to be determined by the Physical Plant and Calvin College.

9.4 Comparison

Our design project is studying the feasibility of a geothermal snowmelt system, so the projected cost of the system must be reasonably accurate. Extensive study will not be done on the other methods of snow melting, so only a rough comparison between geothermal and other methods will be presented, based on past investigation. The desired outcome of our project will be to have a design that will allow us to reasonably state the feasibility of the project based on practicality and cost.

9.5 Budget

Our budget is found in Table 7. We are in the process of looking for external funding for our project.
Table 7: Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Projected Cost</th>
<th>Notes</th>
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<tr>
<td>Microcontroller</td>
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<td>Thermocouples</td>
<td>$50</td>
<td>For in-ground winter temperature measurements</td>
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<tr>
<td>Piping (Heat Capture)</td>
<td>$20</td>
<td>HDPE</td>
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<tr>
<td>Piping (Heat Dissipation)</td>
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<td>HDPE</td>
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<td>Water Pump</td>
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<tr>
<td>Electronic Components</td>
<td>$110</td>
<td>Sensors, etc.</td>
</tr>
<tr>
<td>Building Materials</td>
<td>$140</td>
<td>Wood, plastic, fasteners, Concrete, etc.</td>
</tr>
<tr>
<td>Soil</td>
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<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$500</strong></td>
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</table>

9.6 Challenges

9.6.1 Right of Way

One anticipated problem with implementing this system has to do with the property line. The City of Grand Rapids owns the right-of-way on Burton St, and this means that Calvin would have to obtain encroachment permits before installing a snowmelt system. This will need to be communicated to the Physical Plant if they decide to implement a snowmelt system at the entrance.

9.6.2 Operating Induced Hazards

If a snowmelt system is under-designed or improperly operated, the system can do more harm than good. Under certain wind speed and air temperature conditions, weak snowmelt systems are only able to melt a portion of the snow. The unmelted portions form icy layers that are more hazardous than unmelted snow. For this reason, it is crucial that snowmelt systems be designed to handle wide ranges of snowfall conditions.
In some extreme cases, it is possible that temperatures will become so low that the snowmelt system is unable to melt the snow at an acceptable rate. In this case, the best response is to shut down the system, producing two benefits. The first benefit is to increase safety. A snowmelt system that does not completely melt snow and ice would make the entrance even more dangerous. A second advantage of turning off the system at these temperatures would be to save energy: running an ineffective snowmelt system is wasting energy. Under these extreme conditions, it will be necessary to plow the entrance before turning on the system again.

10. Conclusion

Our preliminary analysis and research shows that a snowmelt system using geothermal heat pump is a viable option for the Burton Street Entrance. However, further analysis will be necessary to determine whether or not a system without a heat pump is viable. Regardless of the results of this analysis, team GEOmelt plans to share the insights learned through this project to inform Calvin College and the public about the benefits and drawbacks of using geothermal methods to melt snow.

We believe that the unique makeup of our team will be a benefit to our success in this project. With our variety of backgrounds, we can provide necessary technical skills for both the design of the entrance and the implementation of the model. Therefore, this project is feasible for team GEOmelt, and we will continue our work throughout the spring semester at Calvin College.
Appendix 1: ASHRAE Standards

Table 8: Heat Output and Mean Fluid Temperature for Hydronic Snow-Melting

(Mean fluid temperature based on 12 in. tube spacing)

<table>
<thead>
<tr>
<th>$s$</th>
<th>$A_r$</th>
<th>$q_o$ ($t_s = 0^\circ F$)</th>
<th>$t_m$ ($t_s = 0^\circ F$)</th>
<th>$q_o$ ($t_s = 10^\circ F$)</th>
<th>$t_m$ ($t_s = 10^\circ F$)</th>
<th>$q_o$ ($t_s = 20^\circ F$)</th>
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<td>108 135 159</td>
<td>76 86 94</td>
<td>67 67 67</td>
<td>65 65 65</td>
<td>63 63 63</td>
<td>61 61 61</td>
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<td>203 244 282</td>
<td>171 197 221</td>
<td>136 146 155</td>
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<td></td>
<td>0.0</td>
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<td>129 129 129</td>
<td>125 125 125</td>
<td>121 121 121</td>
<td>100 100 100</td>
<td>98 98 98</td>
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<td>308 363 414</td>
<td>275 317 354</td>
<td>241 268 292</td>
<td>204 214 223</td>
<td>187 215 240</td>
<td>171 192 210</td>
<td>154 167 179</td>
<td>136 140 144</td>
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<td>134 134 134</td>
<td>131 131 131</td>
<td>127 127 127</td>
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Appendix 2: Snowmelting Parameters

Table 9: Monthly Average Humidity for Three Cities

<table>
<thead>
<tr>
<th>Average Morning Relative Humidity (%)</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>Grand Rapids Michigan</th>
<th>Grand Rapids vs. Buffalo</th>
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<tr>
<td>January</td>
<td>75</td>
<td>79</td>
<td>82</td>
<td>3</td>
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<td>February</td>
<td>75</td>
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<tr>
<td>March</td>
<td>74</td>
<td>79</td>
<td>80</td>
<td>1</td>
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<td>April</td>
<td>72</td>
<td>75</td>
<td>78</td>
<td>3</td>
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<tr>
<td>May</td>
<td>74</td>
<td>75</td>
<td>78</td>
<td>3</td>
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<tr>
<td>October</td>
<td>84</td>
<td>81</td>
<td>85</td>
<td>4</td>
</tr>
<tr>
<td>November</td>
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<td>December</td>
<td>78</td>
<td>80</td>
<td>83</td>
<td>3</td>
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<tr>
<td>Average Winter Morning Humidity</td>
<td>76.75</td>
<td>78.375</td>
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<table>
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<th>Average Afternoon Relative Humidity (%)</th>
<th>Portland Maine</th>
<th>Buffalo New York</th>
<th>Grand Rapids Michigan</th>
<th>Grand Rapids vs. Buffalo</th>
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<tbody>
<tr>
<td>January</td>
<td>60</td>
<td>72</td>
<td>73</td>
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<tr>
<td>February</td>
<td>56</td>
<td>65</td>
<td>68</td>
<td>-1.0</td>
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<tr>
<td>March</td>
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<tr>
<td>May</td>
<td>58</td>
<td>55</td>
<td>53</td>
<td>-2.0</td>
</tr>
<tr>
<td>October</td>
<td>53</td>
<td>60</td>
<td>61</td>
<td>1.0</td>
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<tr>
<td>November</td>
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<tr>
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<td>74</td>
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<tr>
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<td>58</td>
<td>64.5</td>
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Table 10: Monthly Average Wind speed for Three Cities

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<td>14</td>
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<td>13.1</td>
<td>11.1</td>
<td>-2</td>
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<td>12.3</td>
<td>11</td>
<td>-1.3</td>
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<td>May</td>
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<td>11.4</td>
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<td>8.4</td>
<td>11.1</td>
<td>9.4</td>
<td>-1.7</td>
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<tr>
<td>November</td>
<td>8.8</td>
<td>12.6</td>
<td>10.5</td>
<td>-2.1</td>
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<tr>
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<td>9</td>
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<td>10.7</td>
<td>-2.4</td>
</tr>
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<td>Annual Average Windspeed</td>
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Appendix 3: U.S. Snowmelting Requirements.

Figure 14: Snow-Melting Loads Required for a Snow Free Area Ratio of 0.0

Figure 15: Snow-Melting Loads Required for a Snow Free Area Ratio of 1.0
# Appendix 4: Schedule

<table>
<thead>
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<th>Task Name</th>
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<th>April</th>
<th>May</th>
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<td>11/21</td>
<td>11/22</td>
<td>11/29</td>
<td>12/6</td>
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<td>12/11</td>
<td>12/18</td>
<td>1/2</td>
<td>1/9</td>
<td>1/21</td>
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<td>1/7</td>
<td>1/10</td>
<td>1/17</td>
<td>2/14</td>
<td>2/21</td>
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<tr>
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<td>1/13</td>
<td>1/16</td>
<td>1/23</td>
<td>2/2</td>
<td>2/9</td>
<td>2/16</td>
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<td>Install Thermocouples</td>
<td>2/25</td>
<td>3/1</td>
<td>3/8</td>
<td>3/15</td>
<td>3/22</td>
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<td>Setup appointments with Physical Plant</td>
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<td>Investigate Calvin Snowmelt Systems</td>
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<td>Interim Break</td>
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<td>Contact Engineering Firms for Specs</td>
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<td>Research Local Snowmelt Systems</td>
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<td>Key Semester Scheduling Meetings</td>
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<td>Prepare 3rd Class Presentation</td>
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<tr>
<td>Design Model</td>
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<tr>
<td>Attain Parts for Model</td>
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<tr>
<td>Begin Building and Testing the Model</td>
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<td>Preliminary Blueprint Designs for Calvin</td>
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<td>Attain Cosmetic Parts for Model</td>
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**Figure 16: Gantt Chart**
Appendix 5: EES Calculations

"Initial Snow-melt analysis"
"4 Nov, 2009"

"Problem Layout:
Introduction
Inputs
System Constants
Heat loss calculations
Heat transfer calculations
System specific calculations"

"Introduction"
"The snowmelt area and the outside conditions will be used to calculate the heat loads that the system will demand.
With a calculation system developed to tell details of how the snowmelt system will respond to certain conditions,
decisions can be made such as: how far the pipes need to be spaced apart, how many parallel loops of pipe there
needs to be, and the fluid temperatures that need to be delivered to have the desired effect."

"Inputs based on outside conditions"
Rate_snowfall = 2 [cm/hr]
V_air = 2[m/s]
"Windspeed will affect convective coefficient, and still needs to be accounted for."
T_air = -1[C]
T_concrete = 3[C]
T_final = -1[C]
SpecificGravity_snow = 0.13
"A variable based on conditions, changes with the wetness of the snow"

"Constants of System"
L_pipe = 100[m]
D_pipe = 0.02[m]
N = 6
SA_concrete = 324[m^2]
English_SA = 3485[ft^2]
SI_surface_area = English_SA * (1[m])^2 / (3.2808[ft])^2
T_melt = 0[C]
"The melting temperature of water"

"Convective Heat Loss"
Q_dot_conv = h*A_s*(T_s - T_infinity) * 1[kW] / 1000[W]
h = 15[W/m^2-C]
A_s = SA_concrete
T_s = T_concrete
from"
T_infinity = T_air
"Temperature of the air that heat is transferred to"

"Radiative Heat Loss"
Q_dot_rad = e*sigma*A_s*((T_s + 273[K])^4 - (T_surr + 273[K])^4) * 1[kW] / 1000[W]"Equation for Radiative heat loss"
\( e = 0.5 \)
\( \sigma = 5.67 \times 10^{-8} \times 1[W/m^2/K^4] \)
\( T_{\text{surr}} = T_{\text{air}} \)

"Combined Heat Loss"
\( Q_{\text{dot total}} = h_{\text{combined}} \times A_s \times (T_s - T_{\text{infinity}}) \)

"Energy to melt snow"
\( T_{\text{snow}} = T_{\text{air}} \)

"Snow temperature will be the same as the air temperature"
\( D_{\text{ensity snow}} = \text{SpecificGravity}_{\text{snow}} \times \text{Density}_{\text{water}} \)
\( D_{\text{ensity water}} = 1000[kg/m^3] \)
\( R_{\text{ate vol}} = \text{Rate snowfall} \times \text{SA\textunderscore concrete} \times 1[m]/100[cm] \)
\( R_{\text{ate mass}} = \text{Rate vol} \times \text{Density}_{\text{snow}} \times 1[hr] / 60[min] \times 1[min] / 60[sec] \)
\( G_{\text{ravity}} = 9.81[m/s^2] \)
\( E_{\text{nergy ice}} = \text{Rate mass} \times \text{Cp}_{\text{ice}} \times \Delta T_{1} \)

"Mass rate times the specific heat of ice times the temperature difference of the ice and the melting temperature"
\( C_{\text{p ice}} = \text{SpecHeat(Ice}, T=T_{\text{air}}, P= 101.325[kPa]) \)
\( \Delta T_{1} = T_{\text{air}} - T_{\text{mel}} \)
\( E_{\text{nergy melting}} = H_{\text{fs}} \times \text{Rate mass} \)

"Enthalpy of phase change from solid to fluid times the mass rate that is being melted."
\( H_{\text{fs}} = \text{Enthalpy\textunderscore fusion(Water)} \)
\( E_{\text{nergy liquid}} = \text{Rate mass} \times \text{Cp}_{\text{liquid}} \times \Delta T_{2} \)

"Mass rate times the specific heat of water times the temperature difference of the water and the final temperature"
\( C_{\text{p liquid}} = \text{SpecHeat(Water}, T=T_{\text{final}}, P= 101.325[kPa]) \)
\( \Delta T_{2} = T_{\text{mel}} - T_{\text{final}} \)
\( E_{\text{nergy snowmelt}} = E_{\text{nergy ice}} + E_{\text{nergy melting}} + E_{\text{nergy liquid}} \)

"Total Heat Loss"
\( E_{\text{nergy total}} = E_{\text{nergy snowmelt}} + Q_{\text{dot rad}} + Q_{\text{dot conv}} \)

"Energy from pipe through concrete"
\( Q_{\text{dot[1]}} + Q_{\text{dot[2]}} + Q_{\text{dot[3]}} + Q_{\text{dot[4]}} = E_{\text{nergy total}} \)

"Heat transfer calculations, sections defined by the drawing of the snowmelt areas."
"Section 1"
"Approx. 15' x 38'"
\( Q_{\text{dot[1]}} = N[1] \times S[1] \times k[1] \times \Delta T_{3[1]} \times 1[kW]/1000[W] \)

"Energy transferred per pipe pass"
\( S[1] = 2 \times \pi \times L[1] \times (2 \times w[1]) / (\pi \times D[1]) \times \sinh(2 \times \pi \times z[1] / w[1]) \)

"Conduction shape factor"
\( L[1] = 15[ft] \times 1[m] / 3.2808[ft] \)
\( w[1] = 10[in] \times 0.0254[m/in] \)
\( D[1] = D_{\text{pipe}} \)
\( z[1] = 2.5[in] \times 0.0254[m/in] \)
\( k[1] = 1.00[W/m-C] \)
\( S[1] = 15[ft] \times 38[ft] \times (1[m]) / (3.2808[ft])^2 \)
\( \Delta T_{3[1]} = T_{\text{pipe}} - T_{\text{concrete}} \)

"The length of one pipe pass"
"Center to center distance between pipes"
"Distance from surface to the center of the pipe"
"Thermal conductivity of concrete"
"Temperature difference between the pipe and surface of the concrete"

"Section 2"
"Approx. 26' x 44'"

"Energy transferred per pipe pass"
\( S[2] = 2 \times \pi \times L[2] \times (2 \times w[2]) / (\pi \times D[2]) \times \sinh(2 \times \pi \times z[2] / w[2]) \)

"Conduction shape factor"
L[2] = 26[ft]*1[m]/3.2808[ft]
w[2] = w[1]
D[2] = D_pipe
z[2] = 2.5[in] * .0254[m/in]
k[2] = 1.00[W/m·C]
SA[2] = 26[ft]*44[ft] * (1[m])^2 / (3.2808[ft])^2
DELTAT[3][2] = T_pipe - T_concrete

"The length of one pipe pass"
"Center to center distance between pipes"
"Distance from surface to the center of the pipe"
"Thermal conductivity of concrete"
"Temperature difference between the pipe and surface of the concrete"

"Section 3"
"Approx. 27' x 44'"

S[3] = 2*Pi*L[3]/ln((2*w[3])/(Pi*D[3]) * sinh(2*Pi*z[3]/w[3]))
L[3] = 27[ft]*1[m]/3.2808[ft]
w[3] = w[1]
D[3] = D_pipe
z[3] = 2.5[in] * .0254[m/in]
k[3] = 1.00[W/m·C]
SA[3] = 27[ft]*44[ft] * (1[m])^2 / (3.2808[ft])^2
DELTAT[3][3] = T_pipe - T_concrete

"The length of one pipe pass"
"Center to center distance between pipes"
"Distance from surface to the center of the pipe"
"Thermal conductivity of concrete"
"Temperature difference between the pipe and surface of the concrete"

"Section 4"
"Approx. 15' x 35'"

D[4] = D_pipe
z[4] = 2.5[in] * .0254[m/in]
k[4] = 1.00[W/m·C]
SA[4] = 27[ft]*44[ft] * (1[m])^2 / (3.2808[ft])^2
DELTAT[3][4] = T_pipe - T_concrete

"The length of one pipe pass"
"Center to center distance between pipes"
"Distance from surface to the center of the pipe"
"Thermal conductivity of concrete"
"Temperature difference between the pipe and surface of the concrete"

"System specific calculations: Flow and temperature of heating fluid"

Energy_total = M_dot * Cp_total * DELTAT4
Cp_total = 0.5*Cp_ethanol + 0.5*Cp_liquid
Cp_ethanol = SpecHeat(Ethanol,T=T_pipe,P=200[kPa])
DELTAT4 = 10[C]

"The total energy transfer from the heating fluid will be the flow rate times the specific heat times the change in temperature of the fluid."

"Temperature drop calculations for Section 1"

HL_area = Energy_total / SA_concrete
TperM = HL_area / PL_area / (M_dot * Cp_total)
Tdrop_total = TperM * PL_total
passes through the pipe."

"Heat loss per unit area"
"Pipe length per unit area"
"Total length of pipe through section one"
"Temperature drop per meter of pipe length"
"Total drop in temperature after fluid completely passes through the pipe."
Appendix 6: EES Solutions

A_s=324 [m^2]  L_pipe=100 [m]
Cp_ethanol=2.694 [kJ/kg-K]  M_dot=4.151 [kg/s]
Cp_ice=2.15 [kJ/kg-K]  N=6
Cp_liquid=2.15 [kJ/kg-C]  PL_area=3.937 [1/m]
Cp_total=2.422 [kJ/kg-K]  PL_total=208.5 [m]
DELTAT1=-1 [C]  Q_dot_conv=19.44 [kW]
deltaT2=1 [C]  Q_dot_rad=3.023 [kW]
DELTAT4=10 [C]  Rate_mass=0.234 [kg/sec]
Density_sn=ow=130 [kg/m^3]  Rate_snowfall=2 [cm/hr]
Density_water=1000 [kg/m^3]  Rate_vol=6.48 [m^3/hr]
D_pipe=0.02 [m]  SA_concrete=324 [m^2]
e=0.5  sigma=5.670E-08 [W/m^2-K^4]
Energy_ice=-0.5032 [kW]  SI_surface_area=323.8 [m^2]
Energy_liquid=0.5032 [kW]  SpecificGravity_snow=0.13
Energy_melting=78.06 [kW]  Tdrop_total=1.634 [C]
Energy_snowmelt=78.06 [kW]  TperM=0.00784 [K/m]
Energy_total=100.5 [kW]  T_air=-1 [C]
English_SA=3485 [ft^2]  T_concrete=3 [C]
Gravity=9.81 [m/s^2]  T_final=-1 [C]
h=15 [W/m^2-C]  T_infinity=-1 [C]
HL_area=0.3103 [kW/m^2]  T_melt=0 [C]
H_fs=333.6 [kJ/kg]  T_pipe=40.32 [C]
SI_surface_area=323.8 [m^2]  T_s=3 [C]
SpecificGravity_snow=0.13  T_snow=-1 [C]
Tdrop_total=1.634 [C]  T_surrr=-1 [C]
V_air=2 [m/s]