Project Proposal and Feasibility Study

Team 3: GeoEphex

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Executive Summary

Renewable energy sources, energy efficiency, and sustainable development are gaining popularity in the media and in the lives of everyday Americans. Senior design team 3, GeoEphex, has the unique opportunity to take part in the development of renewable energy sources on a local level. Calvin College’s Professor Gerard Venema wants to join the movement towards increased use of renewable energy. As he begins designing an energy efficient home for the Grand Rapids area, he has given GeoEphex the task of designing a heating and cooling system for the house. He requests that the heating and cooling system be powered in an environmentally responsible way, specifically requesting geothermal technology. In addition to his commitments to environmental sustainability, the client also places value on financial stewardship.

To decide upon the best option for the heating, ventilation, and air conditioning (HVAC) of the client’s home, many HVAC systems have been investigated. These systems are not limited to geothermal technologies; rather conventional systems were explored to find the best economic and environmental design for the client. Two major decisions play into the ultimate design decision. First, a heating (and cooling) source was selected. The heat source alternatives included:

- Vertical Closed Geothermal System
- Horizontal Closed Geothermal System
- Horizontal Coil Geothermal System
- Oil Furnace and Air Conditioning
- Gas Furnace and Air Conditioning
- Boiler and Air Conditioning

Second, the delivery system was selected. This consists of the components that distribute heat and air conditioning through the house. These alternatives included:

- Forced Air
- Radiant Heat
- Hot Water Radiators

Design Team 3 recommends that a vertical closed geothermal system be used in conjunction with a forced air delivery system. After obtaining specifics on the size and design of the home, calculations will be done to determine the size of the required HVAC system. From this information, a detailed design will be formulated including the following:

- Geothermal Well Field Layout
- Heat Pump Requirements
- Piping Specifications
- Heat Transfer
- Delivery System Size and Design

Additionally, a cost analysis will compare the proposed geothermal system to a conventional system. This will ensure financial feasibility and allow the client to make a well informed decision.
# Table of Contents

1 Customer Profile ........................................................................................................... 1  
2 Project Definition ........................................................................................................... 1  
3 Design Specifications ...................................................................................................... 1  
4 Alternative Solutions/Feasibility Study .......................................................................... 2  
  4.1 Closed Systems .......................................................................................................... 2  
  4.1.1 Horizontal Systems ............................................................................................. 2  
  4.1.2 Vertical Systems ................................................................................................. 2  
  4.1.3 Pond Systems ...................................................................................................... 3  
  4.1.4 Horizontal Coil Systems ..................................................................................... 3  
  4.2 Open Systems ........................................................................................................... 4  
  4.3 Conventional Systems ............................................................................................... 5  
  4.3.1 Furnaces .................................................................................................................. 5  
  4.3.2 Boilers .................................................................................................................... 5  
  4.3.3 Electric Radiators .................................................................................................. 6  
  4.4 Distribution Systems ................................................................................................. 6  
  4.4.1 Delivery Systems ................................................................................................ 6  
  4.4.2 System Configurations ......................................................................................... 8  
  4.5 Preferred Design ...................................................................................................... 8  
  4.5.1 Decision Matrices ................................................................................................ 8  
  4.6 Snow Melting System ............................................................................................... 11  
5 Preliminary Design .......................................................................................................... 11  
  5.1 Soil Properties ........................................................................................................... 11  
  5.1.1 Strata ..................................................................................................................... 11  
  5.1.2 Thermal Properties .............................................................................................. 12  
  5.2 Load Calculations ..................................................................................................... 12  
5.3 Site Development ...................................................................................................... 13  
  5.3.1 House Position ................................................................................................... 13  
  5.3.2 Utilities ................................................................................................................ 13  
  5.3.3 Tentative Field Layout ......................................................................................... 13  
6 Cost Estimates .................................................................................................................. 13  
  6.1 Variable Costs .......................................................................................................... 13  
  6.1.1 Conventional ........................................................................................................ 13  
  6.1.2 Geothermal .......................................................................................................... 14  
  6.2 Capital Costs ............................................................................................................. 15
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2.1</td>
<td>Conventional Systems .......................................................... 15</td>
</tr>
<tr>
<td>6.2.2</td>
<td>Geothermal Systems .................................................................. 15</td>
</tr>
<tr>
<td>6.3</td>
<td>Permits .................................................................................. 15</td>
</tr>
<tr>
<td>6.4</td>
<td>Grants, Tax Exemptions, Incentives ......................................... 15</td>
</tr>
<tr>
<td>6.4.1</td>
<td>Federal ................................................................................. 15</td>
</tr>
<tr>
<td>6.4.2</td>
<td>State .................................................................................... 16</td>
</tr>
<tr>
<td>6.4.3</td>
<td>Utility Company ...................................................................... 16</td>
</tr>
<tr>
<td>6.5</td>
<td>Payback Period ...................................................................... 16</td>
</tr>
<tr>
<td>7</td>
<td>Task Breakdown ...................................................................... 17</td>
</tr>
<tr>
<td>7.1</td>
<td>Gantt Chart ........................................................................... 17</td>
</tr>
<tr>
<td>7.2</td>
<td>Design and Installation Schedule ........................................... 17</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Drilling Companies .................................................................. 17</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Heat Pump Manufacturers .......................................................... 18</td>
</tr>
<tr>
<td>7.2.3</td>
<td>HVAC Requirements .................................................................. 18</td>
</tr>
<tr>
<td>7.2.4</td>
<td>GeoExchange Requirements ........................................................ 19</td>
</tr>
<tr>
<td>7.2.5</td>
<td>Driveway Snow Melt System ..................................................... 19</td>
</tr>
<tr>
<td>8</td>
<td>Acknowledgements .................................................................. 19</td>
</tr>
<tr>
<td>9</td>
<td>References .............................................................................. 20</td>
</tr>
<tr>
<td>10</td>
<td>Appendix ................................................................................ 1</td>
</tr>
</tbody>
</table>
1 Customer Profile

The goal of this project is to create a heating and cooling solution that meets the needs of client, Gerard Venema. The client owns a wooded lot near Reeds Lake where he plans to build a new home; the design is currently in its preliminary stages with plans to break ground in the summer of 2010. The client has employed Design Team 3 to design the climate control system for his home. In an effort to make his home environmentally responsible and to decrease his reliance on gas, the client has expressed interest in geothermal technology. To best serve the client, the options available for economic and sustainable climate control will be researched. The final system will be the one that best fits the client’s needs and the available resources. The system will be tailored to the client’s specific requests and the heating and cooling requirements of his future house.

2 Project Definition

The client based nature of this project establishes that the goals reflect the client’s requests and requirements. A large portion of this project is the research phase. Potential heating and cooling methods must be determined. From this large pool of possibilities, several possibilities must be identified that are feasible given property, cost, and climate constraints. The client has expressed specific interest in a geothermal system. Because many different configurations are available for geothermal systems, these must all be considered. Once a group of feasible geothermal options has been identified, these systems will be compared to conventional heating and cooling systems. This detailed research and design phase will determine the final heating and cooling system.

The heat load of the proposed home is one of the most significant elements in designing the completed geothermal system. Heating and cooling requirements are based on a number of factors including the size of the home, the insulation used, and typical climatic conditions. All of these factors play a role in sizing the heating and cooling system. In addition, a backup heating system needs to be incorporated into the design. In extreme weather, a geothermal system may not be able to produce enough heat to maintain the proper level of comfort in a home. The system may need integrate an electric or gas back up supply in order to insure that the level of comfort the client expects.

Finally, the client needs a detailed cost report. While the client wants the design of his home to reflect environmental responsibility, he also wants to make a wise financial decision. Because of this, cost estimates are an integral part of the design decision. The cost report will detail upfront costs and anticipated annual expenditures. The time that it takes for a geothermal system to pay for itself in conventional heating savings, the payback period, is an important part of the client’s financial considerations.

3 Design Specifications

Three main specifications drive the design of the heating and cooling system for the client. As outlined in section 2, the heating and cooling load is a major factor in design. Several load calculations will define this specification. Once the load is determined, the system can be sized appropriately. The second specification is cost. The client wants a geothermal system that is financially feasible. Design Team 3 will design a system that has a lower overall cost than a conventional system. This specification will direct many design decisions. Lastly, environmental responsibility will be a part of the heating and cooling system design. This specification is more difficult to measure quantitatively than the previous
two. However, the Christian values of the client and of Design Team 3 make this an important qualification. Potential systems will be compared based on emissions, use of renewable resources, and ecosystem preservation.

4 Alternative Solutions/Feasibility Study

4.1 Closed Systems

There are several types of closed geothermal systems including horizontal, vertical, pond, and horizontal coil pipe loops. In a closed system, the same fluid continually circulates through an underground piping system, typically High Density Polyethylene (HDPE) plastic pipe, which when fused together does not leak and can last 30-50 years\textsuperscript{1}. The fluid usually consists of water and antifreeze solution. The antifreeze agent prevents the liquid from freezing which would render the system inoperable. At moderate depths, the ground remains at a relatively constant temperature of 46°F\textsuperscript{2}. During the winter, when the air temperature is colder than that of the ground, the fluid in the underground pipes gains heat. An above ground heat pump extracts the heat from the fluid. The cooled liquid then returns to the ground where it again gains heat so that the cycle can continue. In the summer, when the air temperature is warmer than the ground temperature, this process operates in the reverse fashion. The warm fluid in the pipes is cooled underground, enabling the system to remove heat from the house.

4.1.1 Horizontal Systems

The difference between horizontal and vertical systems is the placement of the pipes in the ground. Horizontal pipes are placed in relatively shallow trenches 4-8 feet deep and 3-10 feet wide. To provide more pipe length while digging up the same amount of lawn, pipes are sometimes run at two levels, one sitting several feet above the other. These systems tend to be less expensive because they do not require complex digging, in general they cost roughly between $1,800 and $2,200, even though they actually require more pipe than a vertical system because ground temperatures closer to the surface are less stable. The main drawback of these systems is that they require a large area of ground, anywhere between 3,000 and 7,500 square feet of lawn space\textsuperscript{3}.

4.1.2 Vertical Systems

Alternatively, vertical systems take very little surface area. 4 bore holes spaced roughly 20 feet apart each can heat a typical home. The downside is that digging can be much more expensive. Vertical closed loop pipes run two lengths of pipe connected at one end by a U-shaped bend down bore holes. These holes are typically 60-200 feet deep and roughly 6 inches in diameter. After the pipes are in place the hole is filled with clay grout which insures good contact with the soil and prevents the contamination of surface water. The depth of the holes required and soil type dramatically affect the cost of installation. If the soil is clay all the way down, installation is typically $2,000-$2,500, but if rock must be excavated, the cost can rise to $3,500-$4,000. If the ground is made up of differing layers of sand, rock, and clay the cost increases dramatically, in the range of $11,000-$16,000\textsuperscript{3}.

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\textsuperscript{1} Pahl (See entry beginning with “Pahl” in the Section 8, References)
\textsuperscript{2} McQuay
\textsuperscript{3} Chiras
4.1.3 Pond Systems

Another option for geothermal heating and cooling is a pond system. In a pond system, coils of pipe are placed in a natural or artificial body of water. The water must be easily accessible, within 200 feet of the site. To protect the piping and ensure sufficient water contact, the coils must be eight to ten feet underwater.\(^4\) Pond systems are highly efficient because of the water’s ability to transfer heat. The installation of pond systems requires little excavation or drilling. If feasible, a pond system can be very low cost.

Several problems present themselves when considering using a pond system for the client’s property. Although Reeds Lake is in close proximity to the client’s lot, the lake is the property of the city of East Grand Rapids. At this location, the lake is shallow and swampy, not suitable for the installation of geothermal coils. Additionally, the client’s property is situated across the road from the lake. It is not feasible to run geothermal coils under preexisting roadway. The client’s lot location in relation to the Reeds Lake and the unfavorable characteristics of this section of the lake prevent the use of a pond system for geothermal heating and cooling.

4.1.4 Horizontal Coil Systems

A variation of the closed loop horizontal configuration incorporates coils. Rather than using several long stretches of pipe, this system uses coils of pipe as shown below in Figure 1: Horizontal Coils.\(^5\) Similar to the horizontal system, this configuration requires digging trenches. However, the coil method allows for a shorter trench, giving it an advantage over the traditional horizontal system. Because this configuration requires less trench area, the cost of excavation decreases, resulting in an installation costs that is lower than for the traditional horizontal system.

![Figure 1: Horizontal Coils](image)

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\(^4\) GeoComfort.

4.2 Open Systems

In closed geothermal systems, water or an antifreeze solution continuously circulates through the piping system. In an open system however, the water is only used once. This configuration necessitates access to abundant, high quality surface or ground water. After its use, the water discharges into one of three places: The first place that water may discharge is into surface drainage such as a river or lake. Secondly, the discharge may enter a sub-surface drainage system such as a constructed drain field. The last option is for the discharge to enter discharge well. If the water enters a discharge well it is often re-injected into the aquifer from which it was obtained.\(^6\) The water discharged into the environment is not at its original temperature: in winter, when the water is used to warm the house, it is colder than when it entered the geothermal system. In summer, when it is used to cool the house, the water is warmer than it was originally.

Because it does not require extensive trenches or wells, the installation costs of an open system are often lower than other configurations. Installing this system requires little excavation and no underground coils. If adequate surface water is not available, an intake well is needed. Similarly, if surface water is not available for discharge, a second well is needed for the discharged water as shown in Figure 2.\(^7\)

![Open Loop Systems](image)

**Figure 2: Open System**

Water quality must be high for an open loop geothermal system. The heat pump can experience significant damage if impurities are present in the water. Mineral deposits that accumulate in the heat exchanger lower its efficiency. If the incoming water contains organic matter, sediments build up within the system rendering it inoperable.\(^8\) To ensure suitable quality, the water must be tested for hardness, iron, and acidity. Installing and maintaining a water filter may raise the quality of the water enough to be usable.

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\(^6\) ECONAR.
\(^8\) ECONAR.
Using an open loop geothermal system can have negative environmental impacts. Surface and groundwater hydrology changes when presented with a new, large demand for water. It is possible that water in an aquifer would be used faster than it could replenish, thus depleting this water source. Open loop systems need approximately three gallons of water per minute per ton of cooling capacity to operate. Even if the surrounding land could supply an infinite amount of water, the discharge could change the environment. The addition of slightly warmer or cooler water to an ecosystem changes the natural dynamics. Although the effects are generally small, changes in groundwater temperatures can limit aquatic life and reduce the efficiency of geothermal systems.

4.3 Conventional Systems

4.3.1 Furnaces

Furnaces heat air by electricity or the combustion of natural gas or fuel oil. The heated air is then forced through the house via ductwork. The most common fuel source for furnaces is natural gas. Because the medium of heat transfer is air, corrosion of the ducts does not occur and leakage in the ducts is not a significant concern. Also, the same system of ducts that is used for heating the house can also be used by a central air-conditioning system. Another advantage of using a furnace to heat a house is the fast response time to inputs from the user. When the user changes the thermostat to increase the temperature of the house, a furnace system will provide the requested temperature relatively quickly.

Drawbacks to furnaces exist as well. Using forced air to heat a home can be a noisy process. The inhabitants will be able to hear the system turn on and off from the sound of blowing air. Also, using forced allows only for convective heat transfer. This means that surfaces in the house may feel cold to the touch, especially ground level floors without a basement beneath them. Forced air heating and cooling systems tend to have poor zone control, meaning that different temperatures for different parts of the house may not be attainable. Another minor drawback to a forced air system is the possibility of odor transmission. Odors may be carried from room to room by the moving air through the ducts. Another consideration to be taken into account with a forced air heating system is the necessity of a water heating system. A furnace will heat the house but not the water used by the inhabitants. A secondary water heating system is required.

4.3.2 Boilers

Boilers heat water by the combustion of natural gas or fuel oil. The hot water is then pumped through the house via piping. Heat is transferred from the hot water to the house via radiators. These radiators are often times floor board radiators, meaning that a pipe containing hot water runs along the floor board and heat is dissipated through the use of fins attached to the pipe. Hot water heating systems are versatile and can be implemented in almost any building. The pipes are most often hidden from sight, and a hot water system allows for much more zone control than a forced air system. Another advantage of using hot water to heat the house is that the hot water can also be used directly for cleaning or bathing.

Using a boiler to heat the house has limitations and drawbacks as well. Because water is the medium for heat transfer, corrosion and leakage are significant concerns with a boiler system. Corrosion in the pipes may lead to decreased heat transfer or possibly leaks. Leaks in a hot water system are serious because water can cause major damage in a house. Another downside to a hot water system is the need for radiators that can become nuisance or hazard. Furniture cannot be placed too close to radiators because it will impede the radiators ability to heat the room and because the radiator may reach very high

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9 Alliant Energy.
10 National Ground Water Association.
temperatures, which may become a fire hazard. Hot water systems have a much longer response time to user inputs than forced air systems. Natural convection is the mechanism by which the air is heated in a hot water system, which is a much slower process than the forced convection of a forced air system.

A variation on the conventional hot water system is radiant heating. Radiant heating systems pipe the hot water from the boiler through the floor of the house so that the floor heats up and in turn heats the air. Radiant heating systems remove the sometimes obtrusive radiators that are used in traditional hot water heating systems. They also offer the comfort factor of having warm floors to walk on. Like traditional hot water systems, radiant heating has slow response time.

4.3.3 Electric Radiators

Electric radiators use electricity to heat coils. Fins are attached to the coils and the heat is then dissipated to the air via convection. Electric radiators offer excellent zone control because a separate radiator must be placed in each room. Radiators are easily installed for a relatively low initial cost. However, electric radiators are often obtrusive structures that reach high temperatures resulting in the same concerns associated with floorboard hot water radiators. Also electric radiators do not heat water so an additional water heating system is required for usable hot water.

4.4 Distribution Systems

4.4.1 Delivery Systems

4.4.1.1 Forced Air

There are two main ways to heat the house using a water source heat pump (WSHP). The first is with a forced air system. In this system air is forced over a direct expansion (DX) fan coil and it is heated or cooled. This DX fan coil is heated or cooled by the geothermal water loop. The air then flows through supply ductwork throughout the house and into each room through grilles and diffusers. The air returns to the WSHP through return grilles and return ductwork.

4.4.1.2 Hydronic Floor Radiant

The second system is a radiant heating panel network. A hydronic radiant panel system requires a water-to-water heat pump, which heats water, not air. The water is distributed through a network of pipes throughout the concrete or pyrex floor of the house. Typically this is used in basements with a supplemental air conditioner to provide cooling. A forced air system is generally used in addition to this on upper floors as it is harder to do radiant heating without a concrete floor. But it can be done on upper floors and many companies in the area offer this type of installation.

4.4.1.3 Hydronic Baseboard Radiant

A third way of heating a house is by running hot water through radiators usually located along the floorboards of a room. The water running through the pipes can either be heated by heat pumps or a boiler. One advantage to using hot water to heat a house is the duality of such a system. The hot water can be used to regulate the air temperature in the house as well as provide hot water for cleaning and bathing.
Thirty to sixty percent of a household’s hot water needs can be provided by the desuperheater option on a heat pump\(^\text{11}\). When the heat pump is running, water is directed to a heat exchanger to recover the excess heat, especially when the heat pump is in cooling mode. When the heat pump is in heating mode or is not running, a supplemental electric water heater is used to heat the hot water tank heat for hot water.

Most water-to-air geothermal heat pump suppliers offer the desuperheater as an option on their units. If doing a radiant hydronic system and not a forced air system, some of the hot water from the water-to-water heat pump can just be routed to showers, etc.

4.4.1.4 Electric Radiant

Another type of radiant heating is electric radiant heating. This involves installing a low voltage conductive mesh underneath flooring. The mesh comes in rolls and is simply rolled out and tacked in place and then covered with whatever flooring the customer prefers. The installation cost for this type of heat is less expensive than the hydronic system, but the annual cost is higher, because the customer must pay for electricity to power the system. Most homes do not employ this type of system, although it has all the comfort advantages of radiant heat with the added benefit of easy installation that does not affect the home design\(^\text{12}\).

One major benefit of the radiant system is a better distribution of heat in the room. Because heat rises, supplying heat over the whole surface area of the floor provides better coverage than blowing hot air into the room. Forced air heat flows towards the ceiling, away from living space. Because radiant heat warms the floor where children tend to play, this is a great system for homes with small children. Also, radiant heating systems are often used to heat pools and driveways, which the client has some interest in.

The downside to radiant heating in comparison to a forced air system is that it is more expensive. This cost must be analyzed in comparison to the insulation values of the house to see how much of a benefit it will actually provide.

4.4.1.5 Heat and Energy Recovery Ventilators

Energy Recovery Ventilators (ERVs) and Heat Recovery Ventilators (HRVs) both aid in the recapture of heat usually discarded in bathroom and kitchen exhausts. These systems are integrated in the ductwork of a home and reroute the exiting air past the incoming air. The difference between HRVs and ERVs is how the heat exchanger works. With an energy-recovery ventilator, the heat exchanger transfers a certain amount of water vapor along with heat energy, while a heat-recovery ventilator only transfers heat. ERVs, therefore are the better solution for climates with extreme cold, like West Michigan, because they maintain the humidity level of the home.

ERVs are typically able to recover 70-80% of the energy in the exhaust air and transfer it to the incoming air.\(^\text{13}\) One downside of an ERV is that it requires more maintenance than a typical ventilation system. In order to prevent deterioration of heat recovery, it must be cleaned regularly. An Energy Recovery Ventilator may be an excellent additional measure to improve the efficiency of the client’s

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\(^{11}\) Residential Earth Energy Systems.

\(^{12}\) Sherwood.

\(^{13}\) US Department of Energy “Energy Recovery Ventilation Systems.”
home alongside a geothermal system. An ERV typically costs $800 - $1,600 installed depending on the size of the HVAC system.\textsuperscript{14}

4.4.2 System Configurations

4.4.2.1 One Water Source Heat Pump

Three ways to distribute air with the forced air system were analyzed for the client’s house: one water source heat pump controlling both floors, two water source heat pumps (one per floor), and a variable air and temperature zone damping system.

Using only one heat pump for the entire house is the cheapest option. This is not the most comfortable option, however, since one unit does not have the capacity to control two separate floors. As one floor is usually cooler or warmer than the other, the result is the overheating or overcooling of the floor that is not controlling the thermostat.

4.4.2.2 Variable Volume and Temperature (VVT)

Variable volume and temperature systems make use of zone dampers to control the amount and temperature of air going to different zones in the house. For instance if the basement requires a different quality of air than the upstairs bedroom, the VVT system can account for this. This type of system can meet efficiency requirements for both peak and partial load requirement conditions while keeping the home in a comfortable temperature range.

Adding this system to a single WSHP unit for the home results in a cost similar to, if not cheaper than, two units. The client has a four-zone VVT system in his current house and is very pleased with it.

4.4.2.3 Two Water Source Heat Pumps

Two water source heat pumps provide a significant increase in comfort over one heat pump. Two systems allow each floor to control its own unit based on the temperature it needs, as basements are normally a lot cooler than upper floors. This has a very similar effect to a two-zone VVT system. The downside of this compared to a VVT system is its inability to control more than two “zones” of the house differently.

4.5 Preferred Design

4.5.1 Decision Matrices

4.5.1.1 Heat Source Type

The first major decision of this project is deciding what source will provide heating and cooling for the client’s house. Although the client has an interest in geothermal systems, these systems must be compared to conventional heating and cooling options to ensure that a geothermal system would be financially feasible. The three types of commonly used conventional systems are a gas or oil furnace and a hot water boiler. Because these three systems cannot provide cooling, a forced air delivery system must be installed in conjunction with each of the conventional systems. A pond or an open geothermal system is not feasible for the client’s site as described in sections 4.1.3 and 4.2 respectively. Because these options are not feasible, they are not included in the decision matrix. The three geothermal configurations

\textsuperscript{14} Toolbase Services.
that are possible for the client’s property are a vertical closed system, a horizontal closed system, or a horizontal closed system with coils.

Table 1: Heat Source Decision Matrix

<table>
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<th>Feasibility</th>
<th>Comfort</th>
<th>Design Norms</th>
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<td>Maintenance</td>
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<td>Conventional Systems</td>
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</tr>
<tr>
<td>Coils</td>
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<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1 shows the decision matrix for comparing different heat sources. The design considerations are weighted according to the priorities of the client. The cost, and ultimately the payback period, is one of the most important considerations for the client. He wants an affordable heating and cooling system. Although geothermal systems have a high installation cost, their annual costs are very low. Therefore, for cost, the geothermal systems all scored higher than the conventional systems. A vertical system has a higher initial cost than either of the horizontal systems because of the relatively high cost of drilling wells. Although maintenance is not very difficult for the conventional systems, it is needed periodically. Boilers need more maintenance because of the potential for pipe leaks and corrosion. The underground components for the geothermal systems are projected to last for at least 50 years while the indoor components have a life of 25 years. Because maintenance on the system is so rarely needed, geothermal systems are considered as having no maintenance requirements. The space needed for each system presents an important part of design. Indoors - for the heat pump, furnace, or boiler - each system requires approximately the same amount of space. Outdoors, the space requirements differ drastically. The conventional systems do not require any outdoor space, therefore they received high scores. Because horizontal systems require extensive excavation, they scored the lowest. Response time relates to the time it takes for the client to feel a temperature difference after adjusting the thermostat. Geothermal systems take longer to respond than conventional systems.

The client’s commitment to Christian values and environmental ethics is a driving force in his request for a geothermal system. Because of these values, the effects of each heating and cooling system on the environment and the nearby human populations are important design considerations. Safety for the three conventional systems is more of a risk than for geothermal systems because each of these conventional systems uses a flame which presents fire risk for the house and surrounding land. Because a small amount of electricity is used for the heat pumps associated with geothermal heating, these options are not completely emission free. However, this electricity produces far less emissions than burning gas or oil. If excavation or drilling reaches the level of groundwater, detrimental environmental impacts could ensue. Although the risk of this is very low, vertical systems have more of a potential to change groundwater hydrology than horizontal systems.

As the totals in Table 1 show, a vertical closed system ranks the highest among the options for a heat source. The horizontal closed coil system is an acceptable second option. Because detailed soil

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properties are not known, there is the potential that a vertical system will not be possible. If a layer of bedrock prevents drilling, horizontal coils constitute the alternative heating and cooling configuration.

4.5.1.2 Delivery System

Table 2. Delivery System Decision Matrix

<table>
<thead>
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<th></th>
<th>Weight</th>
<th>Upfront Cost</th>
<th>Annual Cost</th>
<th>Comfort</th>
<th>Maintenance</th>
<th>Effect on Home Design</th>
<th>Geothermal Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Heat Pump</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>830</td>
</tr>
<tr>
<td>Two Heat Pumps</td>
<td>8</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>820</td>
</tr>
<tr>
<td>VVT Zone Control</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>845</td>
</tr>
<tr>
<td>Radiant Floor</td>
<td>2</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>541</td>
</tr>
<tr>
<td>Radiant Baseboard</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>10</td>
<td>591</td>
</tr>
<tr>
<td>Electric Rad. Floor</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>680</td>
</tr>
</tbody>
</table>

The second major design decision is choosing a delivery system. Table 2 shows the decision matrix for this aspect of design. The decision matrix categories were weighted according to the desires of the client. Cost is his most important decision factor. The most expensive system to install is the hydronic radiant flooring followed closely electric radiant flooring. Because these systems stretch over such a large surface area, the upfront installation costs are high. The least expensive to install is the forced air system with one heat pump. It should be noted that the need for ductwork for the forced air systems is not a part of the cost consideration here because ductwork must be in place for every system in order to allow for air cooling in the summer. The second most important factors are efficiency and comfort. Efficiency is closely tied to cost, but better describes the long term benefits of low annual cost. Forced air won the highest scores for this category because of the high efficiency of the heat pumps. Hydronic Radiant Baseboards are the least efficient because they often concentrate their heat at the location of the actual radiator and because the water loses heat as it passes through the baseboard piping. Both Radiant Floor Heating systems score very highly, however, in the comfort category because of the systems’ ability to evenly and constantly distribute heat, with the added luxury of warm floors. Comfort is the area in which each of the forced air heat pump configurations differ. The variable volume and temperature (VVT) heat pump has the ability to control where heat goes in the home making it the most comfortable forced air choice, while one heat pump distributes heat to the whole home blindly making it the least comfortable.

The different systems require different types of maintenance. Forced air requires the frequent but simple maintenance of replacing the air filter. Hydronic radiant flooring should not require any maintenance for a long period of time, but if there is a leak it will be expensive to fix and will cause destruction to the home. The effect on home design category conveys that radiant floor heating requires a special type of flooring which aids the heat distribution through the pipes to the room. This type of flooring is heavier and more cumbersome to install than conventional flooring and limits the flooring options. Forced air with heat pumps necessitates a mechanical room for the heat pumps, while electric radiant floor heating does not affect design at all. Finally, it is important that the distribution system fit with the heat source chosen by our client. Electric heating cannot be powered by geothermal wells, so it
got a low score in that category. This option, however, may be considered as an additional way to heat the floor of a small area such as a kitchen or bathroom without installing a full hydronic radiant system.

The type of distribution system recommended by the decision matrices is a forced air system with VVT Zone Control. This System can be installed for a relatively low cost while still providing the comfort the client desires. The client has expressed that their priorities may change from cost to comfort, in which case the preferred heat delivery system may become hydronic radiant flooring.

4.6 Snow Melting System

The client suggested the possibility of a snow melting system for the driveway. Similar to the radiant floor piping discussed for the home, one type of snow-melt system would involve running hot water or some other fluid such as antifreeze through pipes in the concrete of the driveway.

Typically, driveways in Michigan require about six times the amount of heat load as the home. The temperature of the water would need to be upwards of 100°F to keep up with the heavy snows and winds of this climate. Thus the annual cost of residential snow melting systems is very high. Part of this is due to the need for the water to continually run through the driveway in “idle” mode, so that when snowfall does occur it can quickly respond. If the system is not put in constant idle mode and is instead turned on and off, it may take several hours or even days to gain enough momentum to melt the snow off of the driveway.

Other than adding an additional water-to-water heat pump and additional piping for this hydronic system, the client could also go with an electric snow-melt system. Warmly Yours Inc, an electric cable snow-melt and radiant-panel company, offers an estimate of $11,200 for a 1200 square foot driveway.

5 Preliminary Design

5.1 Soil Properties

5.1.1 Strata

Two existing records contain information about the soil strata on the client’s property. The first record originates from Aqua-Tech Consultants. While the client was deciding whether or not to purchase the lot that they currently own, they consulted this company to determine if the soil was suitable for building. Aqua-Tech obtained a core sample of the soil at the northeast corner of the lot to a depth of 25 feet. Table 3 summarizes their findings. The second record is a water well record of a neighboring property. Well drilling information must be documented with the proper authorities, in this case the Michigan Department of Public Health. Table 4 lists the well information of 3218 Reeds Lake Boulevard, the property northwest of the client’s lot.

### Table 3: Soil Strata Log

<table>
<thead>
<tr>
<th>Auger Depth (ft)</th>
<th>Soil Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 to 0.5</td>
<td>Topsoil, black</td>
</tr>
<tr>
<td>0.5 to 9.5</td>
<td>Clay, sandy, brown with gray mottling, very firm</td>
</tr>
<tr>
<td>9.5 to 16.0</td>
<td>Clay, brown, trace silt, firm</td>
</tr>
<tr>
<td>16.0 to 25.0</td>
<td>Clay, gray, silty some coarse sand, moist but firm</td>
</tr>
<tr>
<td>Depth (ft)</td>
<td>Soil Description</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------</td>
</tr>
<tr>
<td>0 to 70</td>
<td>Clay</td>
</tr>
<tr>
<td>70 to 100</td>
<td>Sand</td>
</tr>
<tr>
<td>100 to 110</td>
<td>Water bearing formation</td>
</tr>
</tbody>
</table>

5.1.2 Thermal Properties

In the soil, heat is conducted one of two ways. A temperature gradient drives conductive heat transport. Convective heat transport originates from moving groundwater. Fourier’s law describes the conductive heat flux, $H$, as

$$ H = -\kappa \text{grad}(T) $$

where $\kappa$ is thermal conductivity and $T$ is temperature. For clay, the primary component of soil on the client’s lot, the thermal conductivity is 0.2 to 0.3 cal / m-sec-°C. If a horizontal geothermal system is employed, convective heat transport will be the operative method of heat transfer. If a vertical geothermal system is used and if pipe extends beyond 100 feet underground, convective heat transfer due to moving water will impact the system. Convective heat transfer is also driven by temperature, among other properties. Convective heat transfer is calculated as,

$$ H = n*p_w*c_w*T*v $$

where $n$ is soil porosity, $p_w$ is the density of water, $c_w$ is the specific heat of water, and $v$ is the velocity of the groundwater.

These properties of heat transfer in soil will be used to develop a mathematical model of soil heat transfer. Until site specific tests are done, the model will use values for thermal conductivity, groundwater velocity, etc. This model will be used to determine the heat transfer to the pipes and to the fluid in the pipes. From this, the necessary amount of underground pipe will be determined.

5.2 Load Calculations

Based on the architectural plans, load calculations will be run on the house. Figure A1 in the Appendix details the current floor plan for the house. The insulation values of the walls and roof, the window sizes, and the kitchen and laundry equipment, and the weather conditions for Grand Rapids will be taken into account. Using Carrier’s Hourly Analysis Program, cooling and heating loads will be determined. The residential energy code for Michigan is the 2003 IRC (International Residential Code). 

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16 Dominico, Physical and Chemical Hydrogeology.
5.3 Site Development

5.3.1 House Position

The client and architect will determine the position of the house on the property. As the architectural plans are finalized, the location may change slightly. Currently, plans indicate that the house will be on the northeastern half of the property, facing Reeds Lake Boulevard. A driveway, following the northwestern edge of the property, will connect Reeds Lake Boulevard to the house and garage. Figure A2 in the Appendix shows the position of the house on the lot and the surrounding lots. The approximate size of the house is 1600-1800 square feet on the main floor with some additional area in the basement.

5.3.2 Utilities

To build a house on this lot, the client required access to utility lines. Existing power lines run parallel to the northwestern edge of the property. These will be easily accessible for the home but will not interfere with any excavation or drilling needed for a geothermal heating and cooling system. The water main and the sanitary sewer force main enter the client’s property in the southwest corner. Plugs currently block the end of these lines, but they will be removed to connect the client’s future house to existing water systems.

5.3.3 Tentative Field Layout

The client has expressed interest in preserving as much of the existing landscape and ecosystem as possible. The client does not want to disturb native trees and ground cover on the property wherever possible. To do this, the client suggested positioning the geothermal wells or trenches under the patio adjacent to the house. This location limits flora destruction during the excavation of geothermal wells or trenches. However, it could make replacing pipes impractical and expensive. Research will determine common placement of geothermal wells in relation to utilities, buildings, and potable water wells.

Two field configurations exist as discussed in section 4.1: horizontal and vertical. The client’s lot has a slope of 18.8%. The lot is 80 feet by 160 feet. This limited area and high slope makes the option of a horizontal system difficult. If the client installs a horizontal system, the trench depth would vary greatly over its length. A significant portion of the property would need to be excavated, going against the client’s wishes to disturb the landscape the least amount possible. Compared to a horizontal system, a vertical system requires excavating much less land. Although both options will be explored further, a vertical system currently looks more favorable for the client.

6 Cost Estimates

6.1 Variable Costs

6.1.1 Conventional

6.1.1.1 Natural Gas

Natural gas is provided to the Grand Rapids area by two main utility companies, DTE and Consumers Energy. DTE provides gas at a price of $1.02893/Ccf plus a monthly service charge of $8.50\(^\text{18}\). Consumers Energy provides gas at a price of $0.95278/Ccf plus a monthly service charge of

\(^{18}\) DTE Energy, Natural Gas Rates
The energy density of natural gas is 300.3 kWh/Mcf. Using this energy density along with the price per volume of each provider, a price per unit of energy has been determined. Natural gas can be purchased from DTE at a rate of $0.03426/kWh plus monthly charges and from Consumers Energy at a rate of $0.03173/kWh plus monthly charges.

6.1.1.2 Oil

Fuel oil is provided by Crystal Flash Energy. Crystal Flash sells fuel oil at a price of $2.749/gallon. The energy density of fuel oil is 41.0 kWh/gallon. The price per unit of energy for fuel oil from Crystal Flash is $0.06705/kWh.

6.1.1.3 Electricity

Electricity is provided to the Grand Rapids area by three main companies: DTE, Consumers Energy, and Great Lakes Energy. DTE provides electricity at a rate of $0.1072/kWh for the first 17 kWh used per day and $0.1213/kWh for additional kWh. DTE also charges a $6.00 monthly service charge.

Consumers Energy provides electricity at different rates in the summer than the rest of the year. During the months of June to September, Consumers Energy charges $0.0736/kWh for the first 600 kWh per month and $0.1108/kWh for any additional kWh. During the months of October to May, the rate is $0.0736/kWh for all kWh. Consumers Energy also charges a $6.00 monthly service charge.

Great Lakes Energy provides electricity at a rate of $0.09893/kWh and a monthly service charge of $12.00.

6.1.2 Geothermal

Geothermal heat pumps use electricity for energy, so the electricity rates for costing out a geothermal system would be the same as those used for analyzing a conventional electric system. However, if electricity is purchased from DTE, a special geothermal energy rate applies to electricity used by fans, motors, electric water heater, electric resistance heat, and well pumps in the geothermal system. If DTE is selected as the electricity provider, contact customer service at 1-800-477-4747 to make arrangements for the geothermal energy rate.

A typical wellfield costs about $3000/ton. Therefore, depending on the exact system size, this should be around $10,000 for the residence, the anticipated cost of drilling and pipe installation is roughly $13 per foot. The ductwork and equipment costs are detailed in the installation cost analysis.

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19 Consumers Energy, Residential Service Rate A
20 Smith, This Cold House, 78.
21 Smith, This Cold House, 78.
22 DTE Energy, Residential Electric Rates
23 Consumers Energy, Electric Residential Rates
24 Great Lakes Energy
25 Prochaska
6.2 Capital Costs

6.2.1 Conventional Systems

Boilers can be purchased and installed for $3000 to $5000. Furnaces can be purchased for around $1000. Both hot water systems using boilers and forced air systems using furnaces require air conditioning units. Air condensing units cost between $1000 and $2000.

6.2.2 Geothermal Systems

For a three ton unit, approximate installation and annual energy costs are shown in Table 5. For each WSHP, the ductwork is about 60% of the cost, piping is 10%, and the equipment itself is 30%.

<table>
<thead>
<tr>
<th>System</th>
<th>Upfront Installation</th>
<th>Heat</th>
<th>Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 WSHP</td>
<td>24,600</td>
<td>753</td>
<td>192</td>
</tr>
<tr>
<td>2 WSHP</td>
<td>29,000</td>
<td>753</td>
<td>192</td>
</tr>
<tr>
<td>Radiant, WSHP</td>
<td>47,000</td>
<td>753</td>
<td>192</td>
</tr>
<tr>
<td>Natural Gas Furnace</td>
<td>20,000</td>
<td>1,124</td>
<td>130</td>
</tr>
<tr>
<td>Oil Furnace</td>
<td>20,000</td>
<td>1,904</td>
<td>227</td>
</tr>
</tbody>
</table>

6.3 Permits

Due to the client’s property being located within 500 feet of a lake, two permits must be obtained before a geothermal system can be installed. First, a Joint Permit must be filed with the Land and Water Management Division of the Michigan Department of Environmental Quality. Also, a soil erosion permit must be obtained from an appropriate county soil erosion agency. While these permits are essential to the installation of a geothermal heat pump system, they are also required for any disturbance of land within 500 feet of water such as excavation or other procedures used in the construction of a house. For this reason, it is assumed that these permits will be obtained by the construction, excavation, and drilling companies.

6.4 Grants, Tax Exemptions, Incentives

6.4.1 Federal

Two incentives for geothermal heat pump systems are offered by the United States government. One is a tax credit and the other is a grant program. Owners of a geothermal heat pump system are eligible for a tax credit worth 30% of the qualified expenditures of the system. Qualified expenditures include all material costs as well as labor costs for onsite preparation, system assembly and installation, and piping and wiring used to connect the system to the home. The geothermal heat pump installed must meet federal Energy Star requirements to qualify for the tax credit. There is no maximum on the tax credit and if the credit is greater than the tax liability, the extra credit carries over to the next year.

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26 Michigan Dept. of Environmental Quality
27 Michigan Dept. of Environmental Quality
28 N.C. State Univ., Residential Renewable Energy Tax Credit
The second federal incentive for geothermal heat pump systems is a federal grant for 10% of the basis of the property for geothermal heat pumps. However, when a person qualifies for both a tax credit and a federal grant, he or she must receive a tax credit.29

6.4.2 State

The state of Michigan offers tax credits for energy efficient home improvements such as efficient clothes washers, dishwashers, refrigerators, water heaters, and furnaces. Also, tax credits are given for efficient building insulation and windows. The tax credit is for 10% of the installed cost of each improvement with a maximum of $75 each. This tax credit applies only to single persons with an annual income of $37,000 or less or a married couple with joint income of $75,000 or less30. Our client does not qualify for these incentives.

6.4.3 Utility Company

The three utility companies mentioned in Section 6.1 offer various rebate programs for geothermal heat pumps or energy efficient appliances. Great Lakes Energy offers a $500 rebate to their customers for geothermal heat pumps that have a minimum Energy Efficiency Ratio (EER) of 14.1 and a Coefficient of Performance (COP) of 3.331

DTE offers rebates to their customers for energy efficient equipment such as insulation, air conditioners, heat pumps, and furnaces. Rebates are offered for ground source heat pumps that have an EER of 17 or greater32. To qualify for any rebates from DTE, they must first perform an energy audit of the house.

Consumers Energy also offers rebates to their customers for the installation of energy efficient equipment. Consumers Energy does not explicitly include geothermal heat pumps in the list of eligible equipment, but does include heat pumps in general for a rebate ranging from $100 to $35033.

6.5 Payback Period

Using the current cost of electricity, propane, oil, and natural gas, Figure 3 compares the payback period of installing and operating conventional heating and cooling systems to geothermal systems. Current costs of gas, oil, and electricity as detailed in sections 6.1.1.1, 6.1.1.2, and 6.1.1.3 respectively are used for the conventional cost analysis. The geothermal options include one water source heat pump, two water source heat pumps (one per floor), and radiant heating in the basement in conjunction with a water source heat pump on the main floor. The cost analysis for the geothermal options includes federal tax credits as described in section 6.4.1. For this analysis, the tax credit was applied to all installation costs except the ductwork.

Where lines intersect in Figure 3, the overall cost for those systems is the same. This place of intersection is the payback period. For example, in fifteen years, one water source heat pump will be the same cost as a gas furnace. In the years following the WSHP will be less expensive than the gas furnace. Compared to the gas furnace, a system with two water source heat pumps will repay itself in twenty eight years.

29 N.C. State Univ., U.S. Department of Treasury - Renewable Energy Grants
30 N.C. State Univ., Energy Efficient Home Improvements Tax Credit
32 N.C. State Univ. DTE Energy - Residential Energy Efficiency Program
33 N.C. State Univ. Consumers Energy - Residential Energy Efficiency Program
7 Task Breakdown

7.1 Gantt Chart

7.2 Design and Installation Schedule

7.2.1 Drilling Companies

The team has identified five drilling companies in Michigan that are currently certified vertical loop installers by the International Ground Source Heat Pump Association:

- Bariod Industrial Drilling Products
- Detroit Geothermal
- Waldron Well Drilling, Inc.
- Midwest Drill
- ClimateMaster, Inc.

Midwest Geodrill is located in Grand Rapids, making them an attractive option on the basis of convenience and their ability to look at the property before installation. One thing that the team must discuss with potential drilling contractors is their ability to maneuver drilling rigs on the steeply sloped and wooded property. Other information that certified installers could provide is regulations on grout volumes or hole sizes. Also, experienced geothermal installers may have information about earth formations that will assist in the system design of this project.
7.2.2  Heat Pump Manufacturers

7.2.2.1  Trane®

Once the heating and cooling load for the house is determined, heat pump sizes and manufacturers can be specified. Energy Star qualifications for tax credit must be looked into. The Trane® specification for the Axiom™ 1 ½-5 Ton 60-Hz Model GEH/GEV is likely to be an option. For example a 3-ton, vertical, ground source heat pump corresponds to the GEVB036 unit. Other things that would need to be specified is the voltage, type of heat exchanger (coper-water coil or cupro-nickel water coil), the refrigeration circuit (whether or not hot gas preheat, reheat, or economizers will be used), the blower configuration, supply air and return air arrangement, control types, thermostat and sensor location, fault sensor option, temperature sensor option, night setback control, electric heat, filter type, acoustic arrangement, factory configuration, and pricing arrangement.\(^{34}\).

7.2.2.2  Florida Heat Pump Manufacturing

Florida Heat Pump Manufacturing offers residential package units as well. Their units have a capacity of $\frac{3}{4} – 6$ tons, specifically the EC, EM, ES, EV, GS, and GT Series. All of these models work well with geothermal applications.\(^{35}\).

7.2.2.3  Carrier

Carrier also offers geothermal heat pumps. The GT-PX, GT-PG, and GT-G Series are all vertical or horizontal units with variations on refrigerant and scroll compressor type. The GT-PX Split Series, GT-PX Split Series and GT-S Outdoor Split Series are split geothermal units. Carrier also makes water-to-water units for radiant/hydronic applications, the GT-PW High-Temp Series and GT-PW Series.\(^{36}\).

7.2.3  HVAC Requirements

Once the house plans are finalized by the architect, Jim Korf, load calculations can be run on the home to determine the heating and cooling load. Needed for the calculations are the window sizes and insulation values, wall exposure area, wall insulation values, roof insulation values, individual room square footage, basement exposure area, and kitchen and laundry sensible loads. The lighting load is not included, as lights are not typically on during the day and for only a few hours at night. A people load is also not included, as only a minimal number of occupants will only be around, and they will only be around and awake for a few hours at night. The outside air requirements along with everything else will have to be checked according to Michigan’s residential code as of date, the 2003 IRC (International Residential Code).

Once the loads are completed, the equipment must be sized and selected as discussed in section 7.2.2.1. Grilles and diffusers will be placed in each room and sized based on the amount of air needed for the room. Ductwork will be sized and placed in the ceiling structure of the home, and communication with the architect is needed to coordinate the amount of ceiling space in the home.

\(^{34}\) Trane®  
\(^{35}\) Florida Heat Pump Manufacturing  
\(^{36}\) Carrier
7.2.4 GeoExchange Requirements

Once the HVAC sizing has been completed, the sizing of the geothermal well field will come next. The size of the well field is determined from several key factors. A geothermal loop is simply a heat exchanger in which heat is transferred between the liquid running through the system and the earth formation surrounding the system. In order to size the system, the overall heat transfer coefficient must be determined from the resistances of the system. The overall heat transfer coefficient can be calculated from the convective heat transfer coefficient of the system liquid flowing through the tubing combined with the conductive heat transfer coefficients of the HDPE tubing, grout, and earth formation. The thermodynamic properties of the earth formation will vary with depth but the other properties will be fairly constant throughout the system.

Thermal properties of HDPE tubing and grout need to be obtained based on manufacturer specifications. Grout is produced with different compositions to provide different levels of thermal conductivity resulting in a tradeoff between performance and cost. Also, thermal properties of the earth formation on or near the property need to be determined before the geothermal system can be designed appropriately. The team will research previously installed geothermal systems in the area as well as talk with those responsible for the geothermal system installed on Calvin’s campus.

7.2.5 Driveway Snow Melt System

More detailed analysis needs to be done on the possibility of a driveway snow-melt system. Discussion with the companies such as Bylin Snowmelting, Warmly Yours, Royal Radiant Heat, Inc., Snow Tech, etc. to get cost estimates and determine the economic feasibility of this system along discussing with the client his desire to do something like this needs to be done.

The length of pipe running through the driveway, the extra well depth needed, the type of pipe, and the heat loss in the driveway need to be determined.

8 Acknowledgements

Several people have greatly contributed to the progress Team 3 made this semester. These people have advised, informed and directed the team. Special thanks to:

- Professor Sykes – professor at Calvin College and team advisor
- Eric Bratt – engineer with C2AE and industrial consultant
- Jim Korf – architect with Composition Workshop
- Gerard Venema – professor at Calvin College and client of Team 3
- Bill Hromada – HVAC Consultant with R.L. Millies and Associates
- Rick Sprague – Township Planning Director
9 References


Carrier, “Geothermal Heat Pumps.”


Prochaska, Mike, Quote Request, Detroit Geothermal.


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The Customer Choice Coalition. "Electric Rates in Michigan."


Figure A1: Floor Plan