Design of a Modular Heat Exchanger for a Geothermal Heat Pump

A Major Qualifying Project Report

Submitted to the Faculty

Of the

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Degree of Bachelor of Science

By

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Abstract

Through CAD designs, background research, and Thermo designs, this project has taken the first steps in designing a modular heat exchanger to replace horizontal and vertical pipe loops. This document contains a CAD prototype, equations regarding the thermodynamics of the heat pump, and design details for the heat exchanger. Further research, designing, and testing are necessary to make a complete design to be implemented.

Acknowledgements

The successful completion of this project would not have been possible without the contributions of many people. First and foremost I would like to express gratitude to my advisor Professor Christopher Scarpino for his guidance and help in my work on this project. I would also like to thank Cam Crook, WPI Student, for helping with the design the prototype of the coil frame and the aluminum nest which lies at its core.

Table of Contents

Table of Figures

1. Introduction

Geothermal heat pumps are an environmentally friendly and cost effective way to heat up a residential or commercial building. This device heats buildings by transferring heat from within the Earth. In this system, tubing is installed into the ground so that the refrigerant within may extract heat from the Earth and transfer that energy to a building through thermodynamics. Geothermal heat pumps take advantage of the constant temperature found below the surface of the Earth. This heating method is safe. There are no combustion involved, no emission of potentially dangerous gases, and no use of dangerous chemicals.

A geothermal heat pump is an environmentally friendly alternative to non-renewable energy. A problem that occurs with geothermal heat pumps is the time and energy required to fix leakage in the tubing. When the tubing has a leak, the land needs be excavated to find the source of the leakage. This is an expensive time consuming process for a simple maintenance repair.

The objective of the project is to design a modular heat exchanger to replace the current closed loop heat exchanger of a geothermal heat pump system. This new modular system should produce one ton of capacity or 12,000 BTU per hour. The module should be able to connect to other modules in case a building needs multiple units to produce enough heat to warm itself. A person should be able to climb inside the system and access the pipes in case of leakage. This design can be marketed toward residential homes or commercial buildings because it will have the advantages of both the horizontal and vertical closed loop system.

2. Background

Geo thermal heat pumps are capable of heating and cooling homes as well as heat water.[1] The capacity of heat produced by a heat pump is measured in tons. One ton of capacity is twelve thousand BTU per hour. A typical new home uses about three to five tons of heat capacity and two tons cooling.[2] The figure below is the thermo diagram of a heat pump showing the natural flow of a refrigerant in a heat pump. The refrigerant first starts in the compressor where work is added to the fluid, the refrigerant then moves to the condenser where heat is dumped into a heat reservoir. From the condenser, the refrigerant passes through an expansion valve and finally into an evaporator where heat is taken from the cold reservoir. The reservoirs are inside the house and under the ground. The seasons determine which reservoir is inside and which is under ground. For example during the summer, the heat reservoir is underground and the cold reservoir is inside. This means that the refrigerant dumps heat into the ground at the condenser and picks up heat inside at the evaporator.

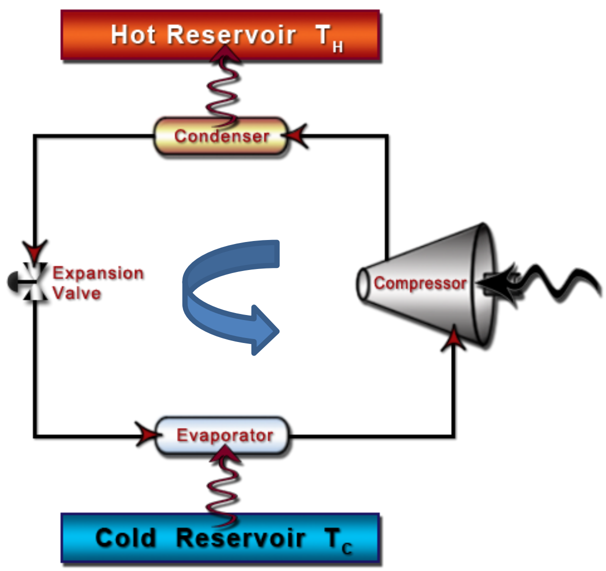

Figure 1: Thermo diagram of a heat pump

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[1] "Geothermal Heat Pumps." *Energy.gov*. Energy Department of the United States, 12 June 2012. Web. 1 Dec. 2014. <http://energy.gov/energysaver/articles/geothermal-heat-pumps>.

[2] Klaassen, Curtis J. N.p.: n.p., n.d. *Geothermal Heat Pump Systems*. Iowa Energy Center, 2006. Web. 10 Dec. 2014. <http://www.michigan.gov/documents/CIS_EO_KC-MAY06-Workshop_159640_7.pdf>.

2.1 How it Works in the summer

A geothermal heat pump transfers heat using the constant temperature of the Earth found a few feet below the surface (nyserda).[3] The system uses the working fluid in its pipes to transfer thermal energy from the ground to a building (nyserda). There are four main components to a geothermal heat pump system (NREL).[4] The first component is a compressor which increases the pressure and temperature of the refrigerant changing the state of the refrigerant from a liquid to a gas. Before going to the second component, the refrigerant goes through a reversing valve which decides which heat exchanger the refrigerant will go, depending on whether the heat pump is heating or cooling a building. The second component is a heat exchanger, also called the condenser. In the condenser, the heat is removed from the refrigerant and is transferred to the Earth causing the refrigerant to condense into a liquid. In the summer, the heat exchanger in the ground becomes the condenser. The third component is the expansion valve. This valve releases pressure in the refrigerant cooling it to a low temperature. The last component is the second heat exchanger called the evaporator. In the last component, the heat transfers from the home to the refrigerant causing the refrigerant to evaporate. In the summer, the heat exchanger in the building becomes the evaporator. After passing the last component, the refrigerant goes to the compressor to repeat the cycle. Figure 2 below shows the heat pump process in the summer time. Figure 3 displays this process in a simpler way using visual aid.

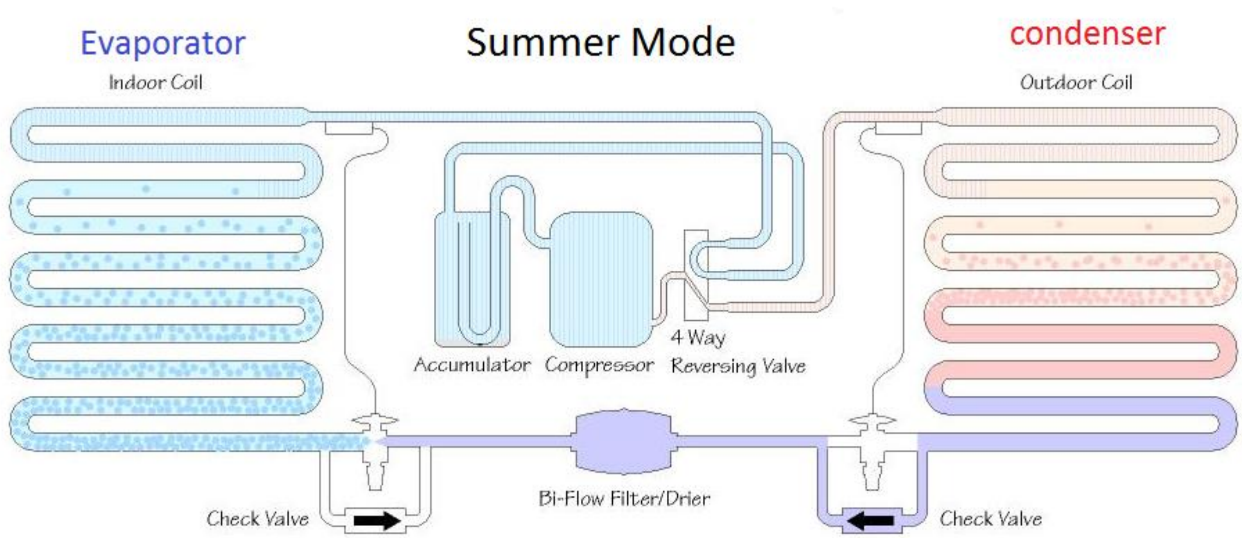

Figure 2: Heat pump process in summer mode

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[3] "Geothermal Heat Pumps." *NYSERDA*. New York State Energy Research and Development Authority (NYSERDA), n.d. Web. 12 Dec. 2014. <http://www.nyserda.ny.gov/Cleantech-and-Innovation/Power-Generation/Geothermal-Heat-Pumps.aspx>.

[4] "Geothermal Heat Pump Basics." *Renewable Energy*. National Renewable Energy Laboratory (NREL), n.d. Web. 12 Dec. 2014. <http://www.nrel.gov/learning/re_geo_heat_pumps.html>.

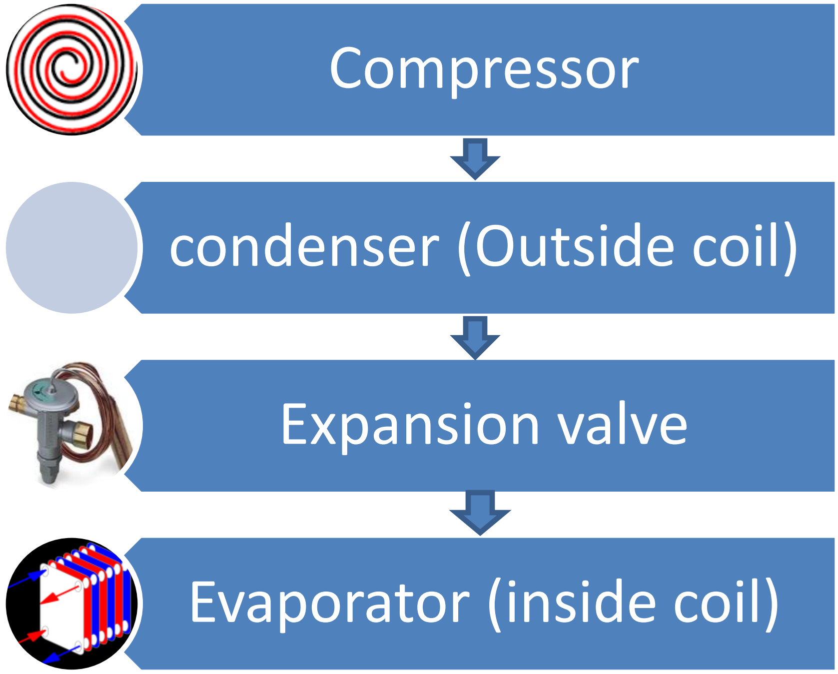

Figure 3: Heat pump diagram in summer mode

2.2 How it Works in the winter

In the winter, the reversing valve switches the path the refrigerant goes. The heat exchangers switch roles. This means that a heat exchanger inside a building becomes a condenser that releases heat into the building and the heat exchanger in the ground becomes an evaporator that absorbs heat from the ground.

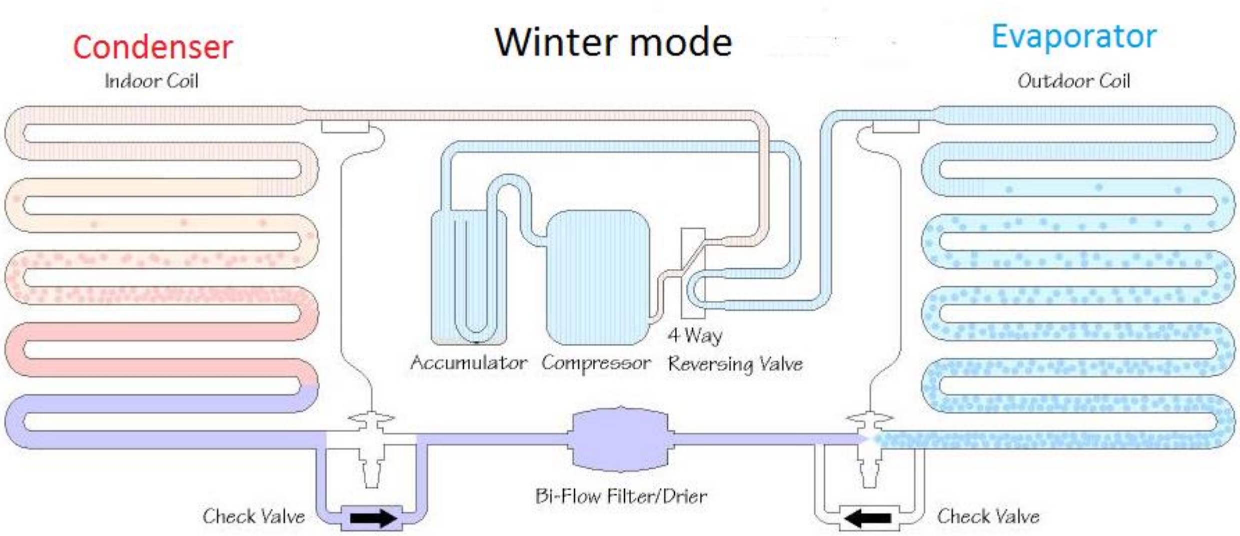

Figure 4: Heat pump process in winter mode

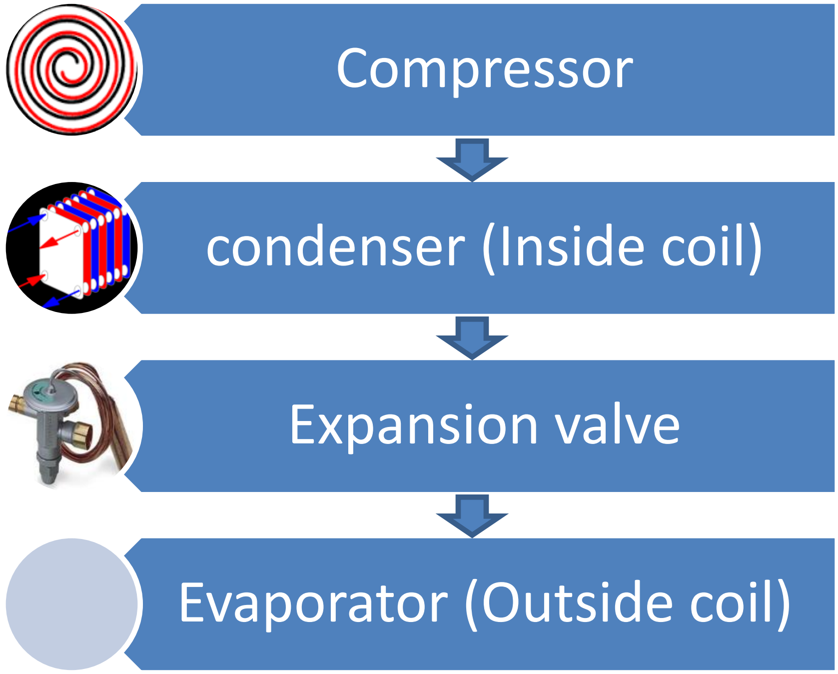

Figure 5: Heat pump diagram in winter mode

2.3 Types of Heat Exchanger

In order for the exchanger to change the refrigerant into a gas, it requires a heat source. There are two different types of heat sources which create two different heat pumps. There are two types of heat pumps which are ground source and air source heat pumps. As the name implies, the difference between the two pumps is whether the heat is attained from the ground or the air. There is one air source heat pump, but multiple ground source heat pumps. These different ground source heat pumps differ in the formation of pipes that are used as a heat exchanger to extract heat from the ground.

There are two types of geothermal heat pumps. These are the closed and the open loop systems. These two types of geothermal heat pumps refer to how the heat exchangers are placed in the ground. Closed loop systems refer to a geothermal heat pump system that only uses the contained fluid within the heat pump to extract heat from the ground. Open loop systems use water within a well as a running fluid. While there is only one type of open loop system, there are three types of closed loop systems.

2.3.1 Horizontal Closed Loop (HCL)

Horizontal closed-loops (HCLs) are pipes laid horizontally to absorb heat from the ground as seen in figure 6. This system is usually used in residential areas because it is more cost efficient for installation, especially for new construction where sufficient land is available.[5] HCL pipes are buried straight or coiled in smaller areas.[6]

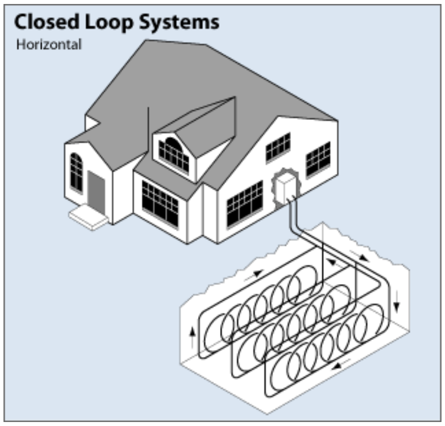

Figure 6: Horizontal Closed Loop System

There are three types of horizontal closed loops. These types are the straight, overlapping slinky and the extended slinky coils type. These systems are only different in how the ground heat exchangers are positioned in the ground. The HCL with a straight pipe is when the pipe is rested in the ground to the end of the trench and brought back to form a single closed loop. The HCL with an extended slinky coil is when a pipe forms slinky coils where the loops don't touch each other. This coil type can be seen in figure 7. The HCL with an overlapping slinky coil is the same as the HCL with extended slinky coils, but has the loops overlapping each other. This coil type can be seen in figure 8.

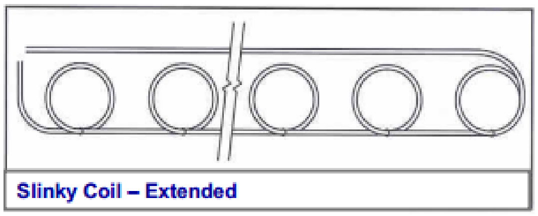

Figure 7: Slinky Coil Extended Type

[5] *Energy.gov*. "Geothermal Heat Pumps." Energy Department of the United States.
[6] California Energy Commission, Efficiency Division, Building Standards Office. 2013. Geothermal Heat Pump and Ground Loop Technologies. California Energy Commission. Publication Number: CEC-400-2014-019.

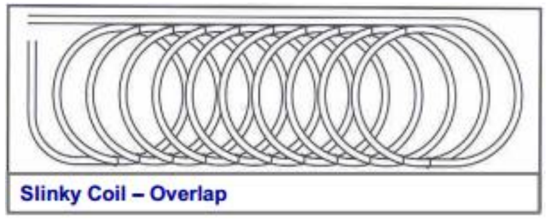

Figure 8: Slinky Coil Overlap Type

HCLs usually need 2500 square foot land area for each ton of horizontal straight closed loops.[7] Trenches for horizontal straight loops are typically 300 feet in length and 6 feet in depth to produce one ton of capacity. The total pipe length used for this trench would be around 600 feet. Trenches for horizontal extended slinky and overlapping slinky coils loops are typically 125 feet in length and 6 feet in depth to produce one ton of capacity. The total pipe length used for this trench would be around 700 feet.[8]

2.3.2 Vertical Closed Loop (VCL)

Vertical closed-loops (VCLs) are pipes that are placed in vertical holes usually because there is not a large enough land area to do HCLs. VCLs are two pipes that form a U-bend loop connection at the bottom of holes that are drilled several hundred feet down below the surface as seen in figure 9.[9] This is usually used by large commercial buildings because the land area for horizontal loops would be expensive.[10]

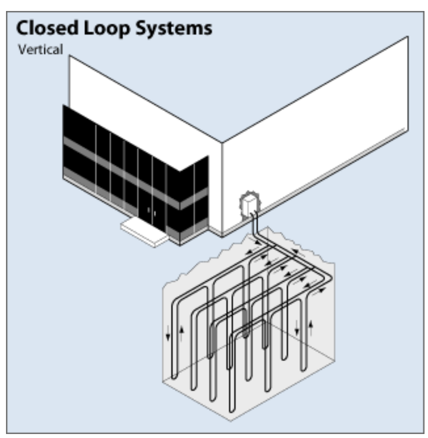

Figure 9: Vertical Closed Loop System

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[7] *Energy.gov*. "Geothermal Heat Pumps." Energy Department of the United States.
[8] Klaassen, *Geothermal Heat Pump Systems*. Iowa Energy Center, 2006. Web.
[9] Michigan DNRE. "Best Practices for Geothermal Vertical Closed-Loop Installations." (n.d.): n. pag. Michigan DNRE, Apr. 2010. Web. 1 Dec. 2014. <https://michigan.gov/documents/deq/dnre-wb-dwehs-wcu-bestpracticesgeothermal_311868_7.pdf>.
[10] *Energy.gov*. "Geothermal Heat Pumps." Energy Department of the United States.

2.3.3 Pond and Lake Closed Loop

Closed loops in Ponds or lakes are the cheapest option of the three closed-loops systems. If there is a pond or a lake near the residential house, the pipes can be coiled and put at the bottom of the pond or lake as seen in figure 6.[11] This system works the same as the other closed systems with only difference being that the closed loops transfer the heat from the pond as well as the Earth to the building.[12] There are requirements that the pond or lake need to match for them to be considered for a closed loop system.[13]

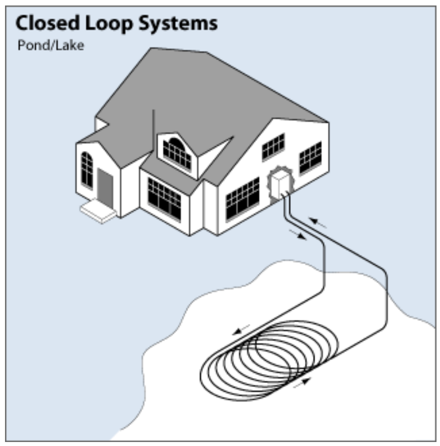

Figure 10: Pond Closed Loop System

Open-loop systems use water in wells as the heat exchange fluid which flow through the system and pour back into the well.[14] This system uses water from the environment and brings it back to the environment usually warmer.[15]

2.4 Components

In this section, the components of a heat pump will be discussed more in detail. The components will be talked about in the winter mode as the thermo diagram below shows. These components are the compressor, condenser, expansion valve, and evaporator.

[11] *Energy.gov*. "Geothermal Heat Pumps." Energy Department of the United States.
[12] California Energy Commission, Geothermal Heat Pump and Ground Loop Technologies.
[13] *Energy.gov*. "Geothermal Heat Pumps." Energy Department of the United States.
[14] *Energy.gov*. "Geothermal Heat Pumps." Energy Department of the United States.
[15] California Energy Commission, Geothermal Heat Pump and Ground Loop Technologies.

2.4.1 Compressor

Figure 4.25 Cut away view of scroll compressor (Emerson Climate Technologies)

Figure 11: Scroll compressor unit

The refrigerant going into a compressor is a cold gas with low pressure. The compressor is responsible for increasing the pressure of the gas through compression and maintaining the rate of the refrigerant flow. Different types of compressors can be used for heat pumps. A modern variant that is being increasingly used is the scroll compressor. The figure below shows the two scrolls that help make up a scroll compressor.

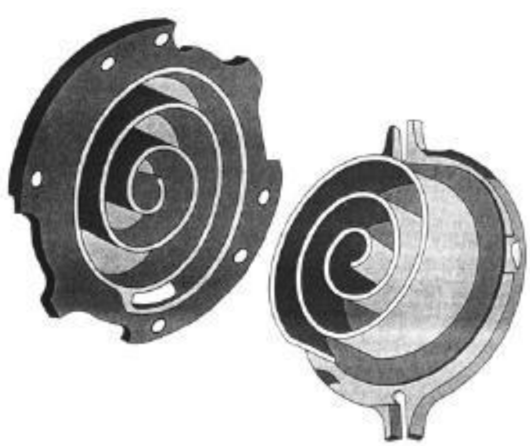

Figure 9-82 Two halves of the scroll compressor. (*Courtesy of Lennox.*)

Figure 12: Two halves of a scroll compressor

The scroll compressor works by having two scrolls. One scroll is fixed and the other scroll orbits the fixed scroll with the help from a motor. The orbiting scroll creates an air pocket between itself and the fixed scroll for the gas from the suction line to enter. As the orbiting scroll circles the fixed scroll, it pushes the air pocket closer to the center of both scrolls. This causes the gas to compress, resulting in an increase of pressure and temperature. Once the gas reaches the center of the two scrolls, it is discharged outward to the discharge connection. The two scrolls as well as the process can be seen in the figures below. The colors represent the air pocket that move closer and closer toward the center. The color of the air pocket becomes darker to show that the refrigerant increases in both pressure and temperature as it approaches the center.

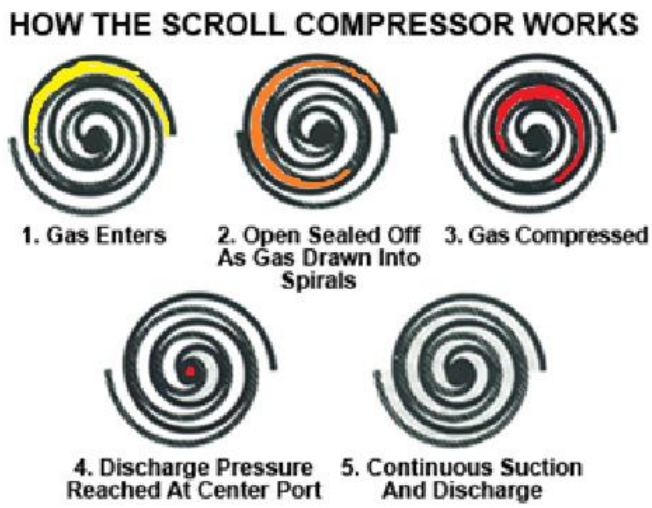

Figure 13: Scroll compressor process

2.4.2 Condenser

Figure 14: Condenser

The condenser for the winter mode is a heat exchanger comprised of a coiled long pipe and fans inside the building. A hot gas at high pressure enters the condenser. As the refrigerant travels through the pipe, fans transfer the heat from the hot high pressurized gas to air ducts. These air ducts transport the heat throughout a building. By the time the refrigerant exits the condenser, it is a cool liquid. The heat released into the building is the sum of the heat absorbed from the evaporator and the work added in the compressor. There are many variations of this heat exchanger that are chosen based off of the size of the building as well as the capacity of heat needed for the building.

2.4.3 Expansion Valve

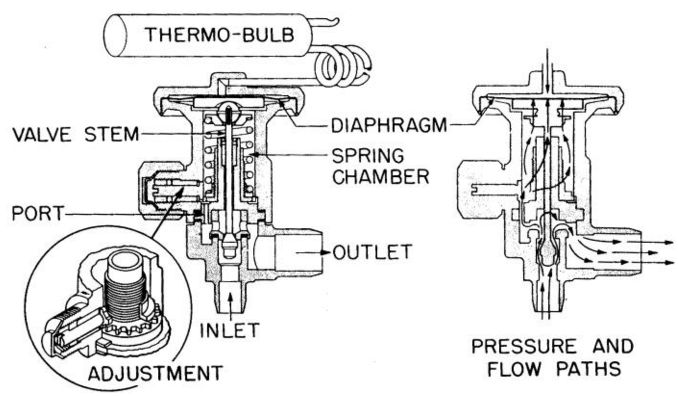

Figure 15: Thermostatic expansion valve

The refrigerant goes into the expansion valve as a cool liquid at high pressure and comes out as a cold liquid gas mixture at low pressure. An expansion valve regulates the pressure of the liquid refrigerant going into the evaporator. There is a sensor at the end of the evaporator to monitor the temperature of the refrigerant. There is a needle in the expansion valve that regulates how much refrigerant passes through the valve based off the temperature at the end of the evaporator. This prevents the refrigerant from reversing flow within the evaporator.

2.4.4 Evaporator

The evaporator for the winter mode would be the modules placed into the ground. The module uses heat transfer to release heat from the water within the module to the refrigerant. This water will be unaffected by the temperature on the surface because it will be in the module 12 feet underground where the temperature of the ground is around 50 F. A liquid/vapor mixture will enter the evaporator and travel through the long spiral tubing within the module. As this happens, heat from the water is absorbed by the refrigerant via heat transfer. By the time the refrigerant exits the evaporator it is a low pressure gas.

3. Engineering Design

This section list the design specifications that I prefer the system to achieve.

3.1 Design Specification

These design specification are split up into two sections describing the goal of this new system. Overall the new system should be more efficient than the current geothermal heat pumps and easier to install and maintain.

3.1.1 Efficiency

- Preferred that one module should be able to produce enough heat for 1 ton capacity

  (12,000 to 15,000 BTU per hour)

- COP (Coefficient of Performance) should be greater than 1

3.1.2 Easier to Install and Maintain

- Should be smaller than 2500 square foot land per ton
- Module should be less than six feet
- Preferred that pipe length be less than 600ft per ton
- Simple instructions to check heat exchanger
- Require minimum ground excavation when compared to horizontal closed loop system
- It should be modular or stackable

3.2 Calculations

This section will discuss the important equations that are needed to be solved for the design of the module. This section is split into two subsections. These sub sections are vapor-compression and design equations. Vapor-compression is a look at the vapor compression cycle and the measurements within dealing with theory of thermodynamics. Design equations are equations used to determine certain dimensions needed for the design of the module.

3.2.1 Vapor-Compression Cycle

First we start with the Vapor-Compression Cycle as seen in the figure below. This cycle describes the flow and cycle of the working fluid within a heat pump. The cycle starts at the exit of the evaporator and the intake of the compressor and moves counterclockwise until it goes back to the intake of the compressor again. The temperatures, pressures, and enthalpy used in this section are based on an approximation of average temperatures, pressures, and enthalpy used for a heat pump. These measurements are subject to change based off of multiple variables including, but not limited to soil type, location, and size of building.

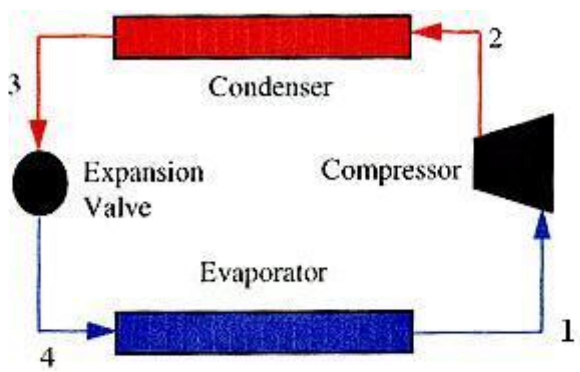

Figure 16: Vapor-Compression cycle

	Point 1: Existing Evaporator	Point 2: Exiting Compressor	Point 3: Exiting Condenser	Point 4: Exiting Expansion Valve
State of Refrigerant	Saturated Vapor	Superheated Vapor	Saturated Liquid	Liquid/Vapor Mixture
Temperature (F)	48	120	120	42
Pressure (PSI)	125	410	410	125
Enthalpy (BTU/Lb)	122	136	65	65

The heat transfer coefficient is very hard to calculate because the refrigerant is changing phase within the heat exchangers.

1-2 Compression	2-3 Condenser	3-4 Expansion Valve	4-1 Evaporator
• Constant Entropy • Adiabatic (q≈0) • Pressure increase • Temperature increase	• No pressure change • Phase change • Vapor to liquid	• Constant Entropy • Adiabatic (q≈0) • Pressure drop • Temperature drop	• No pressure change • Phase change • liquid to Vapor

3.2.2 Design Equations

Design equations are equations conducted to figure out measurements for design materials for the module. These equations were calculated in excel and can be seen in Appendix A.

Copper Pipe Length

$$Q = UA(\Delta T_{LM})$$

Where:

Q= Heat transfer

U = Overall heat transfer coefficient

A= Pipe surface area

$\Delta T_{LM} = \log mean\ temperature\ difference$

$$15000\frac{BTU}{Hr} = \left(70\frac{BTU}{ft^2Hr\ F}\right) * A * \left(\frac{(50-48)-(49-42)}{\ln\left(\frac{50-48}{49-42}\right)}\right)$$

$$A = 53.7\ ft^2$$

$$A = \pi DL$$

$$Length = \frac{A}{\pi D}$$

$$Length = \frac{53.7\ ft^2}{\pi * 0.036\ ft} = 474\ ft$$

This calculation shows how much copper tubing would be needed to produce 15,000 BTU/hr for ACR copper tubing with the outer diameter of 0.5 inches and an inner diameter of 0.436 inches.

Copper Tubing Pressure

The pipe is half inch ACR copper tubing with an inner diameter of 0.436 inches. The copper tubing weights 0.182 Lbs/ft. The total weight of tubing is 86.27 lbs.

Internal Pressure is seen in the equation below.

$$P = \frac{2 * S * t}{D - (0.8 * t)}$$

$$P = \frac{2 * 4000\frac{lbs}{in^2} * 0.032in}{0.5\ in - (0.8 * 0.032in)}$$

$$P = 539\ Psi$$

Where:

P = Internal pressure of copper tubing

S = max allowable stress

T = wall thickness

D = Tubing Outer diameter

The design pressure would be 125 Psi – 410 Psi, so 0.5 inches tubing is ok.

Mass Flow Rate

$$Q_{in} = \dot{m}(h_1 - h_4)$$

$$15{,}000\frac{Btu}{hr} = \dot{m}(122\frac{Btu}{Lb} - 65\frac{Btu}{Lb})$$

$$\dot{m} = 263\frac{Lb}{Hr} = 4.38\frac{Lb}{min}$$

Where:

$Q_{in} = amount\ of\ heat\ absorbed\ by\ each\ coil\ nest$

$\dot{m} = mass\ flow\ rate$

$h_1 = enthalpy\ at\ point\ 1$

$h_4 = enthalpy\ at\ point\ 4$

Scroll Compressor Work

$$Compressor\ Work = \dot{m}(h_2 - h_1)$$

$$Compressor\ Work = 263\frac{lb}{hr}\left(136\frac{btu}{lb} - 122\frac{btu}{lb}\right)$$

$$Compressor\ Work = 3682\frac{btu}{hr}$$

$$Compressor\ Work = 3682\frac{btu}{hr} * \left(\frac{1hp}{2545\frac{btu}{hr}}\right)$$

$$Compressor\ Work = 1.45\ horse\ power$$

Where:

$\dot{m} = mass\ flow\ rate$

$h_1 = enthalpy\ at\ point\ 1$

$h_2 = enthalpy\ at\ point\ 2$

Velocity

$$\dot{V} = \dot{m} * vol$$

$$\dot{V} = 263\frac{Lb}{hr} * 0.466\frac{ft^3}{Lb} = 122.56\frac{ft^3}{hr} = 2.043\frac{ft^3}{min}$$

$$\dot{V} = AV$$

$$122.56\frac{ft^3}{hr} = \left(0.149\ in^2 * \frac{1\ ft^3}{144\ in^2}\right) * V$$

$$V = 118{,}530\frac{ft}{hr} = 1976\frac{ft}{min} = 32.93\frac{ft}{s}$$

Where:

$\dot{V} = Volumetric\ flow\ rate$

$\dot{m} = mass\ flow\ rate$

$vol = volume\ of\ R410a\ at\ 42°F$

$A = area$

$V = vapor\ velocity$

Coefficient of Performance

$$COP = \frac{|Q_H|}{W}$$

$$COP = \frac{15{,}000\ \frac{Btu}{hr}}{3682\frac{Btu}{hr}}$$

$$COP = 4.07$$

$$COP_h = \frac{(h_2 - h_3)}{(h_2 - h_1)}$$

$$COP_h = \frac{(136 - 65)}{(136 - 122)}$$

$$COP_h = 5.07$$

$$COP_c = \frac{(h_1 - h_4)}{(h_2 - h_1)}$$

$$COP_c = \frac{(122 - 65)}{(136 - 122)}$$

$$COP_c = 4.07$$

Where:

COP = Coefficient of Performance

Q_H = Heat supplied to the heat reservoir

W = Work consumed by the heat pump

3.3 Design Details

This section will discuss the specific details of the design of the modular heat exchanger. It will focus on the heat exchanger and not on the heat pump as a whole.

3.3.1 Design Overview

This sub section will discuss what the design overview will look like for a one ton or one module system. This project doesn't include the full analysis of soil or heating capability needed for a building to know how big of a system and prepare the land for the completed ground assemble. A contractor should be used to learn how big of a system is needed to properly heat the building. First a drill would need to make a hole 15 feet in height and at least two feet in diameter. The module would be put in first and would be 3 feet in height. A 12 feet fiberglass cylinder tube would be put in afterwards. Inside the fiberglass cylinder would be 9 feet water insulation to prevent heat from escaping the module. In the middle of the insulation would be the copper tubing coming out of the module. The copper tubing would come out and go through a hole made in the side of the fiberglass to the basement of the build where the heat pump is being held. A manifold is put on top of the insulator. A three feet insulator would be put on top of the manifold. Lastly, an access cover would be put in at the very top as to gain access into the system. This system is seen below.

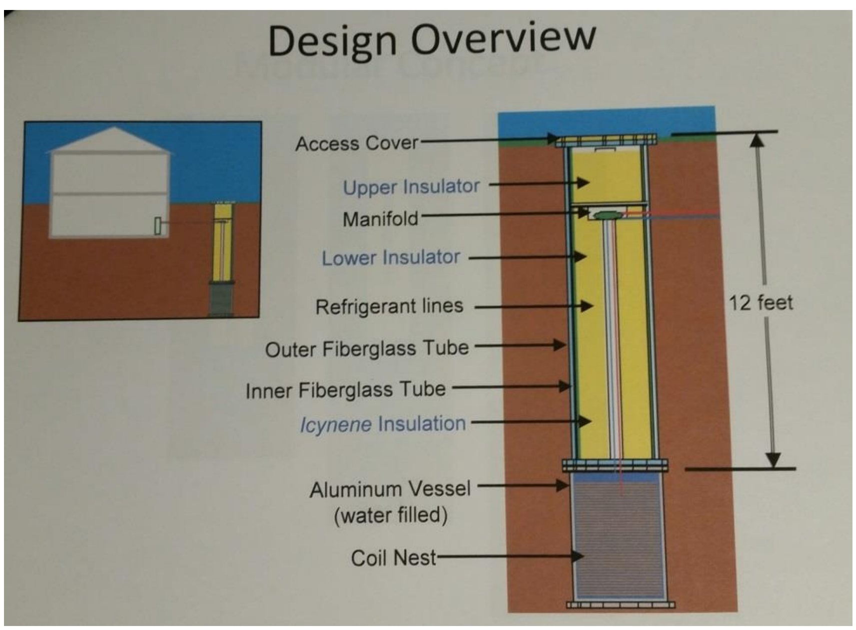

Figure 17: Design overview

3.3.2 Aluminum Cylindrical Module

The module in which the tubing will be placed in is an aluminum cylinder. The purpose of the aluminum cylinder is to encase the water and tubing, so that water doesn't seep into the ground and the tubing can be pulled out more easily. The cylinder will be three feet in depth and two feet in diameter. It will be made of aluminum for its high thermal conductivity which will help promote heat transfer from the ground to the water within the module. This module can be seen below.

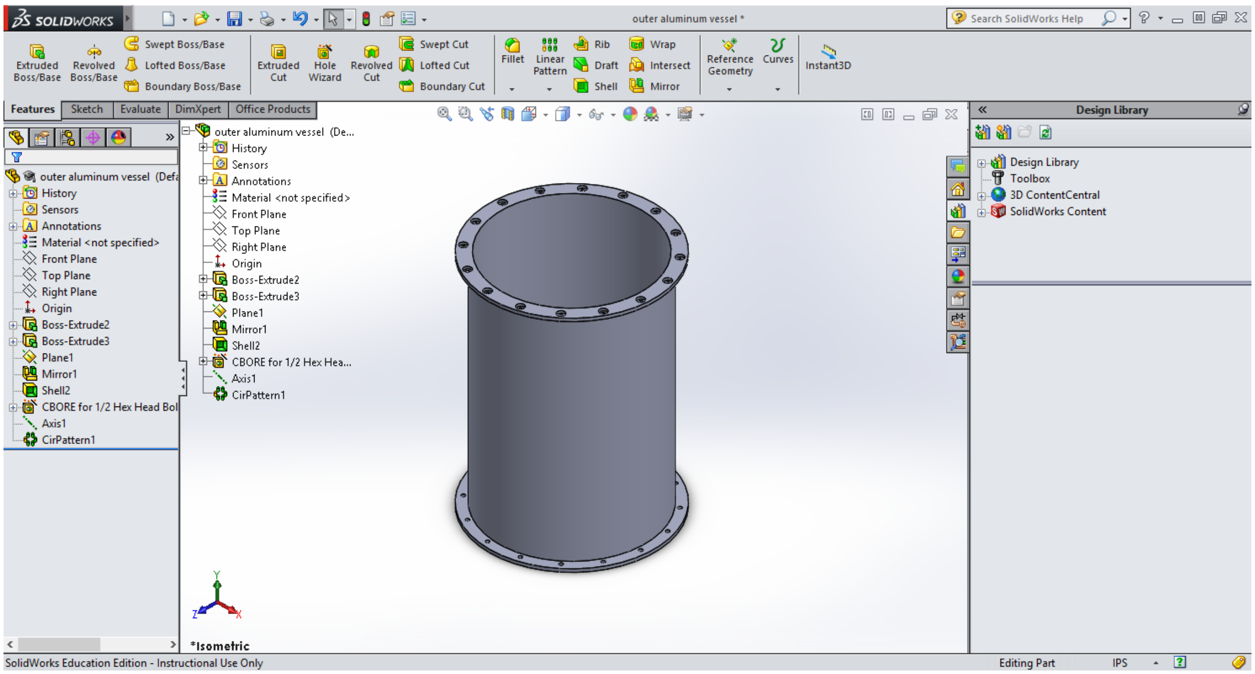

Figure 18: Aluminum cylindrical module

3.3.3 Coil Nest

A coil nest is but one option to hold the tubing within the module. The tubing can be held together zip ties or other straps as long as it keeps the tubing a manageable coil. The purpose of the coil nest is to show more surface area to the tubing within the module so that more surface area is available for heat transfer between the refrigerant and the water. The coil nest will be made from aluminum, for its light weigh, thermal conductivity, and corrosion resistance. My original design for the coil nest was an assembly of a center bar with holes and hooks that could latch onto the holes and hold the tubing. I started out by making a sample of how the assembly would look on a small scale. This is shown in the figure below.

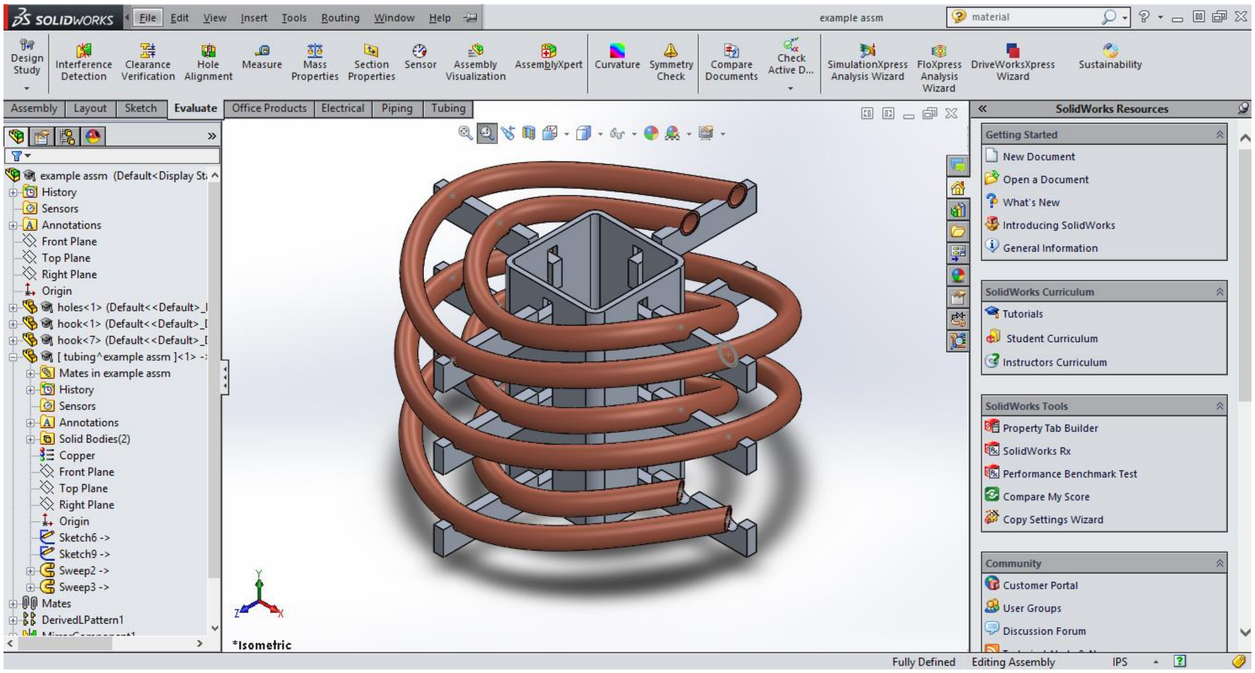

Figure 19: Sample design of hook and bar coil nest

Now that I had made a simple version of the coil nest, I had to modify it so that it can hold at least 474 ft. of tubing. This measurement is the length of tubing needed to produce 15,000 Btu/hour as calculated in the Calculation section. I started by making the length and the width of the center bar 1 ft. so that it may be strong enough to hold the amount of piping necessary. I also added two horizontal holes on the sides of the center bar so that each hook would hold less weight. I wanted the center bar to be smaller than the size of a person so that it wouldn't be too tall. I chose five feet to be a reasonable height. I wanted a hand to be able to fit between the spaces to put the tubing into the hooks. I took measurements of the width of my hand to by 3.3 inches and used this measurement for the spacing needed between each row of holes. With a height of five feet and spacing of 3.3 inches between each row of holes, I was able to fit 18 rows of holes onto the center bar. This change in the center bar can be seen in the figure below.

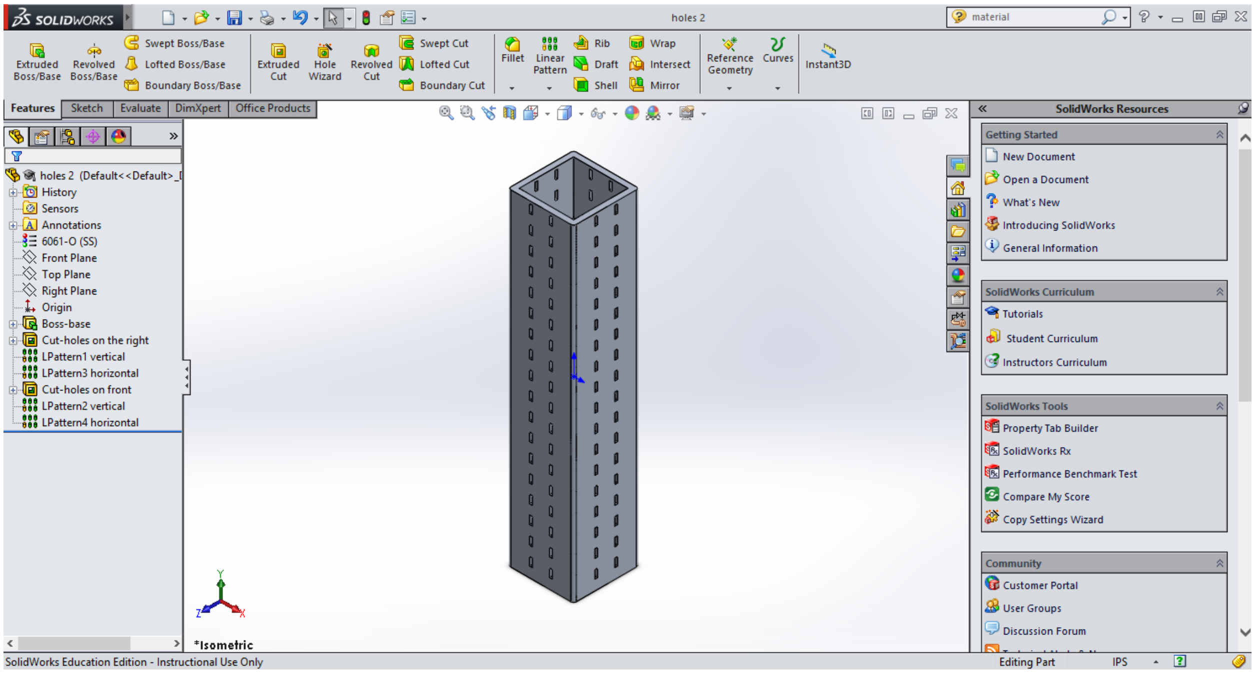

Figure 20: Modified center bar

Now that the center bar was modified for the 474 feet of tubing, next were the hooks that attach to the sides of the center bar. Each notch in the hook is responsible for holding a piece of tubing. The notches are an inch away from the each other. By using excel, I was able to determine that six notches would be enough to hold at least 500 feet of tubing which is more than what we need. This modified hook as well as the modified assembly can be seen in the figures below.

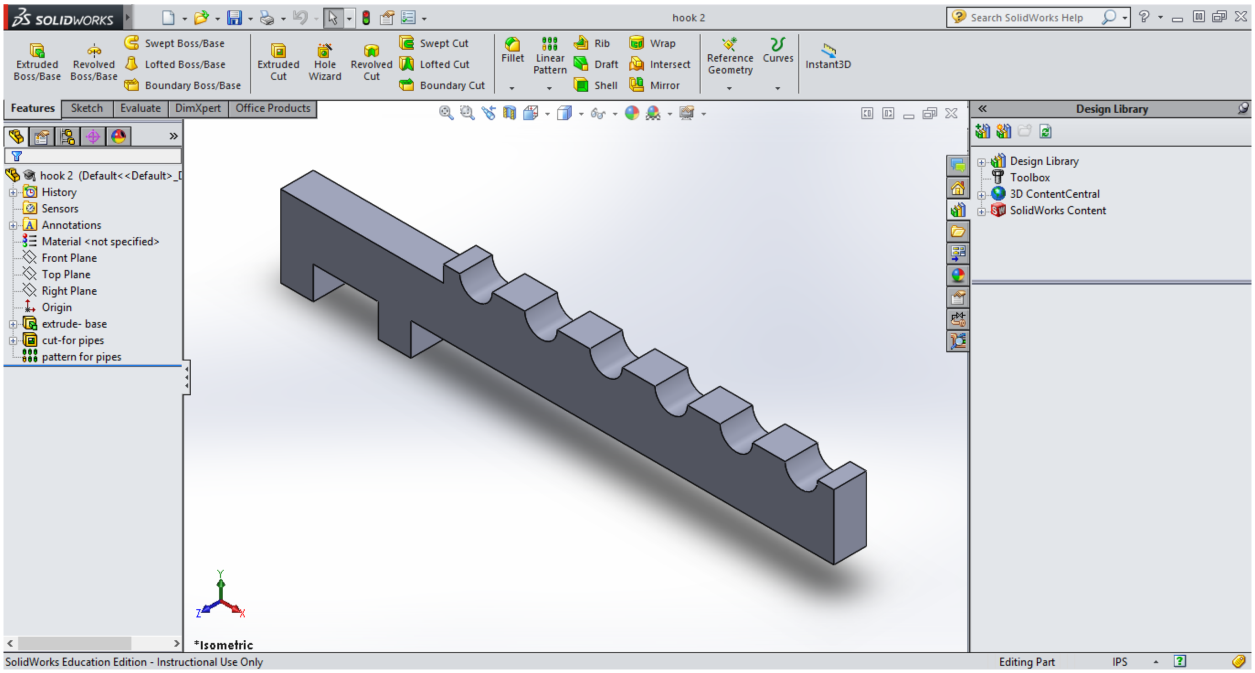

Figure 21: Modified hook

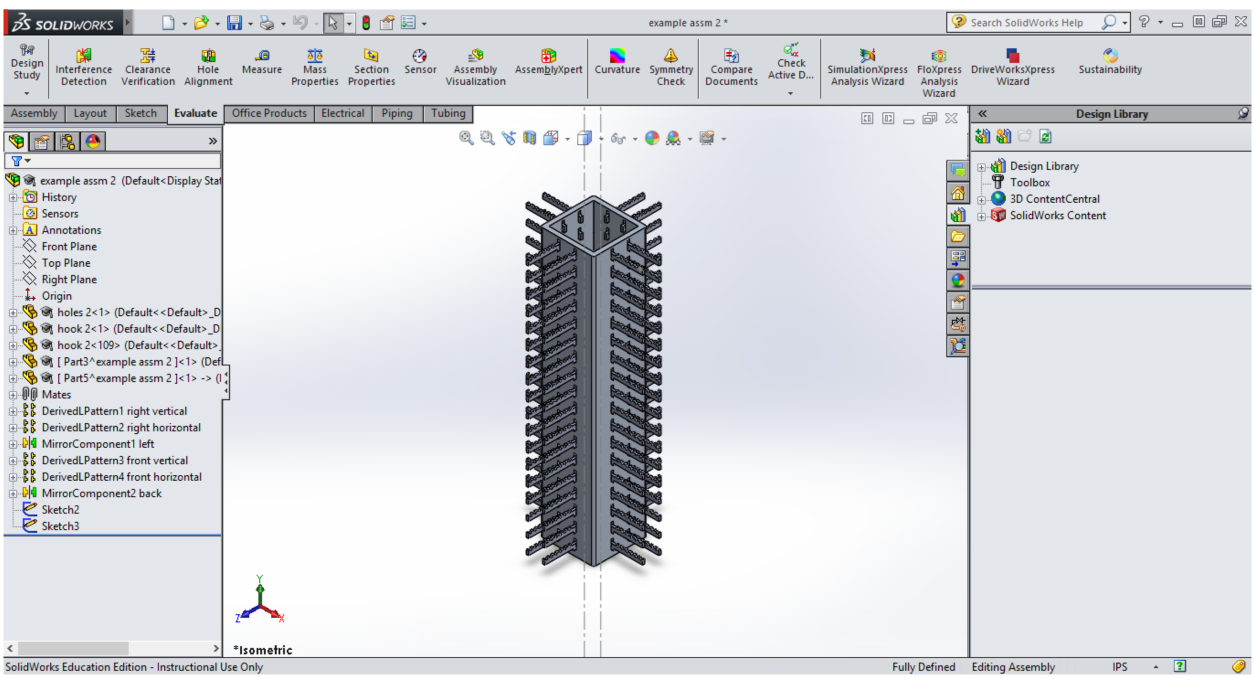

Figure 22: Final hook and bar assembly

3.3.4 Tubing

The material for the tubing in the system will be ACR copper. The purpose of the copper tubing is to hold the refrigerant as it travels to different components. It is made of copper to help absorb heat from the water in the module. The copper tubing will be at least 474 feet as to provide 15,000 BTU/hr of heating to a building.

4. Result

4.1 Efficiency

Goals	Achieve/fail	comment
Preferred that one module should be able to produce enough heat for 1 ton capacity (12,000 to 15,000 BTU per hour)	Achieve	Each module is made to produce at least 15,000 BTU per hour
COP (Coefficient of Performance) should be greater than 1	Achieve	A module has the COP of 4.07

4.2 Easier to Install and Maintain

Goals	Achieve/fail	comment
Should be smaller than 2500 square foot land per ton	Achieve	Around 47.12 square feet for one ton
Module should be less than six feet	Achieve	Between 3 to 5 feet depending on coil nest used
Preferred that pipe length be less than 600ft per ton	Achieve	Around 500 feet per ton
Simple instructions to check heat exchanger	Achieve	There are appendices for yearly maintenance, maintenance every two years, and repairs
Require minimum ground excavation when compared to horizontal closed loop system	Achieve	Only need around 47.12 square feet for one ton as compared to 2500 square feet for closed horizontal loop and 300 square feet for closed vertical
It should be modular or stackable	Achieve	Designed so that each module is able to stack on top of each other and can be bolted together

5. Conclusions

5.1 Overview

The purpose of this project was to design a better alternative for laying down the heat exchangers used in geothermal heat pumps. This design overall means increased efficiency and easier steps to installing and maintaining the system. Calculations were taken, but couldn't be perfected because of changeable variables. This is a design that has the potential to be that great, easy to access heat exchangers, but requires further work.

5.2 Future Recommendations

For a future group to take this module heat exchanger forward, there are a few things that they will need to know or find out. Few of these things are more accurate h needed for more accurate thermo equations. The final design was made based off an estimation of the U and h, but finding a more accurate h could lead to a better design. Another thing the future group should look into is the expense installing and maintaining this modular system. Will it be more cost effective in the long run or is cheaper to install compared to horizontal and vertical closed loop systems? These are questions future groups should find the answer for.

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7. Appendix A: Spreadsheet Equations

[Excel Spreadsheet attached]

variable definition		**List of known variables**	**List of unknown variables**				**equations**		
Pressure	P	D outer = 0.5 in.	Mdot					Q=U*(pi*D*L)(dTlm)	
temperature	T	D inner = 0.036 in.	h1	h2	h3	h4		Qdotin=Mdot(h1-h4)	
volume	V	Qdotin = 15,000 Btu/hour	v1	v2	v3	v4		0=m(h1-h2)+Q-W	
enthalpy	h	T Earth = 50 F	P1	P2	P3	P4		0=m(h2-h3)+Qout-W	
entropy	s		T1	T2	T3	T4		h3=h4	
mass	m		W					0=m(h4-h1)+Qin	
mass flow rate	mdot		Wdot					Qin+W=Q+Qout	
velocity	v		Q	Qout				T2/T1=(P2/P1)^(k-1/k)	
work	W							((Tg-T4)-(Tg-T1))/ln((Tg-T4)/(Tg-T1))	
power	Wdot						heat transfer	Q=2*pi*k*l((Tinside-Toutside)/ln(r2/r1))	
Heat	Qdot								
tube surface area	As								
overall heat transfer coefficient	U								
log mean temperature difference	dTlm								
list of T1 (F)	list of T4 (F)	Qin (BTU/hour)	U	L=Q/(U*dTlm*pi*D) (ft)	h1 (Btu/Lb)	h4 (Btu/Lb)	Mdot=Qdotin/(h4-h1) (Lb/hr)	Mdot (Lb/min)	Q=2*pi*k*l((Tinside-Toutside)/ln(r2/r1))
44	45	15000	70	345.6201789	29.8	121.9	162.8664495	2.714440825	288373.602
45	46			1313.973272	31.3	122.1	165.1982379	2.753303965	
46	47			545.348181					
47	48			128.1041819					
48	49								

Figure 23: Snapshot of Equations

8. Appendix B: Maintenance Instructions

Yearly maintenance includes:

1. Checking and refilling water level in lower vessel if necessary
2. Checking for system leaks
3. Checking refrigerant pressures

Two year maintenance schedule would consist of the following:

1. Use of a safety harness
2. Fencing off work area
3. Removal of the system access cover plate
4. Inspection of access cover plate for structural integrity
5. Removal of the short upper tube insulator
6. Removal of manifold
7. Removal and inspection of the Thermal Expansion Valve
8. Removal of the long upper tube insulator
9. Visual inspection of the top coil nest
10. Visual inspection of the outer aluminum vessel
11. Replacement of the magnesium anode
12. Inspection of the water level sensor

9. Appendix C: Repair Instructions

Immediate access to the installed ground component allows for the "same day repair" of possible coil failures. No matter what time of year. It is possible to access the below ground components. Envisioned, is a repair company that arrives at the customer's home with new (or repaired) ground coil units.

Below is a step by step plan of the retrieval and repair of the ground coil units.

1. Use of a safety fall harness
2. Fence-off work area
3. Removal of the unit's access cover plate
4. Remove short upper tube insulator
5. Disconnect and remove of manifold and Thermal Expansion Valve
6. Remove long upper tube insulator
7. "Cut" copper tubing just "above" coil unit with long reaching cut-off tool
8. Remove straight lengths of cut tube
9. Grasp upper coil plate with "retrieval claw"
10. Use gantry to retrieve top coil from the lower aluminum vessel
11. Generally, the bad coil is replaced with another new (or repaired) coil
12. All previously "cut" copper lines would be re-soldered above ground
13. Re-attach water level sensor to new coil
14. Attach new magnesium anode
15. The replacement coil would then be lowered back into the lower vessel
16. Fill the outer aluminum vessel with water
17. Reinstall the long upper tube insulator
18. Hook up the copper lines to manifold and Thermal Expansion valve
19. Reinstall the short upper tube insulator
20. Reinstall the unit's access cover place