EML 4905 Senior Design Project

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REQUIREMENT FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

HYBRID GEOTHERMAL HEAT PUMP SYSTEM

Final Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Henry Gutierrez, Santiago Paz, Miguel Friere and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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ABSTRACT

A geothermal heat pump system uses thermal energy to provide cooling during the summer or heating during the winter. It works under the same principles as an air conditioner but it utilizes constant underground temperature to efficiently perform this [19]. Around the earth, about 5 to 6 feet (2 meters) under the ground and regardless of the outside temperature, there is a moderate temperature range from 50°F to 60°F [5]. This range allows the geothermal pump to act as a heat sink during the summer and as a heat source during the winter. The Florida International University (FIU) Solar House is connected to this type of pump. However, during extremely hot days in South Florida, the excess heat leaving the pump lines is not being wasted effectively. Therefore, to accommodate to the hot weather, a cooling tower will be introduced to efficiently remove heat leaving the pump lines prior to entering the geothermal loops. This auxiliary heat rejecting system is the reason for which the geothermal heat pump is a hybrid one.

Figure 1 FIU Solar House [6]

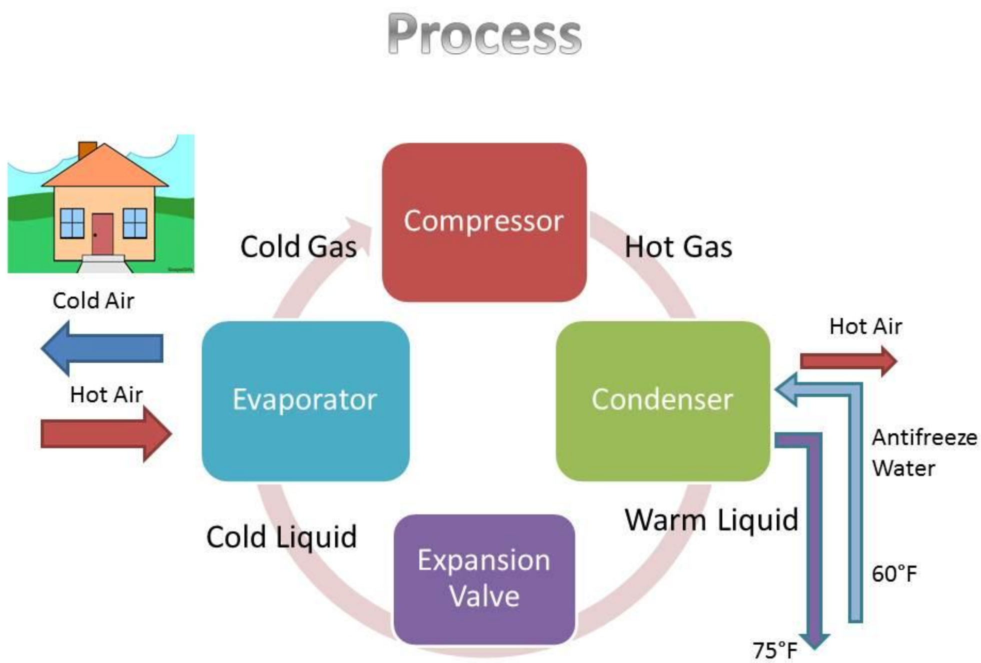


Figure 2 Geothermal Heat Pump Process [8]

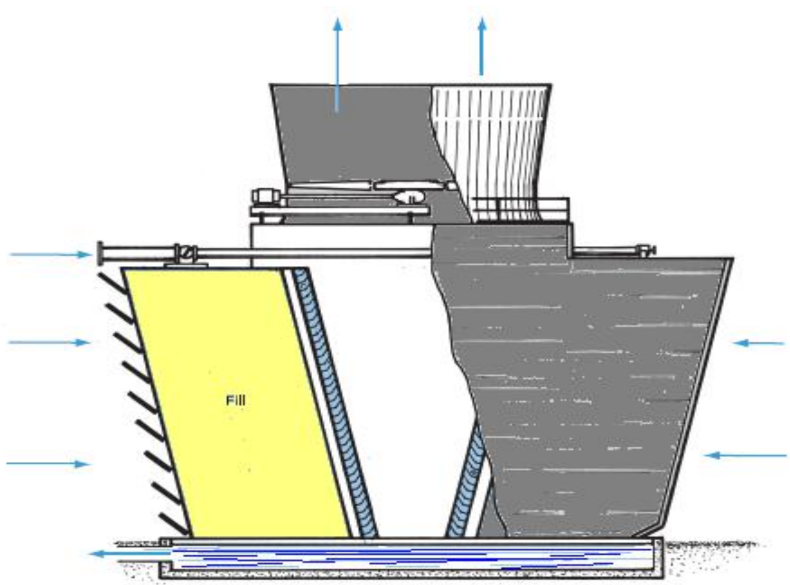


Figure 3 Geothermal Heat Pump Process [11]

INTRODUCTION

PROBLEM STATEMENT

The solar house at FIU uses a geothermal heat pump for cooling and heating process. Geothermal energy is used to reject the heat from the house back into the ground. Many slinky tube loops that contain refrigerant are laid are installed under the ground to accomplish this process [19]. Inside the tubes, refrigerant R410-A circulates changing the temperature from one point to the other as it travels underground. Therefore it acts as a heat exchanger. One of the problems with the FIU Solar House is that in Miami, FL the average temperature is around 95 degrees Fahrenheit which doesn't allow the heat to dissipate quickly enough.

As the temperatures rise during the summer, the heat flow from the inside the house to the ground is huge. During the process of heat balance on summer days, the ground becomes hotter and the process cannot complete appropriately. The area where the pipes were originally buried, due to space restrictions, is not large enough to dissipate the heat required to cool the house.

There is a solution to this problem. This is to increase the area of pipes under the ground and incorporate a cooling tower. Adding more pipes will dissipate the extra amount of heat needed to cool the house. In addition, during the winter time the extra energy needed will be lost. A cooling tower is an auxiliary heat rejecting system to dissipate the extra heat during the summer time. With the cooling tower, a shut off valve will be designed to activate the tower during the summer time when temperature is high facilitating the heat transfer in an efficient way. During the winter, the cooling tower will be off in order to save energy and not energy loss.

MOTIVATION

Geothermal heat pump industries have been increasing for recent years [9]. The market is growing and more people are changing from a traditional air condition units to a geothermal heat pump saving money for during time. In addition, the geothermal pump is the most effective environmentally friendly solution. With the new way of cooling or heating process a problem arise in each situation as our problem and solution will come up in different approach; the cooling tower. This new system has the most effective of heat removal and low operation cost. The geothermal pump uses different type of energy from the ground like heat in case of volcanic activity, water flow in a river and the different temperature between the ground and the surface. The applications of the geothermal pump are extending for all country making a big market to exploit using the new technology.

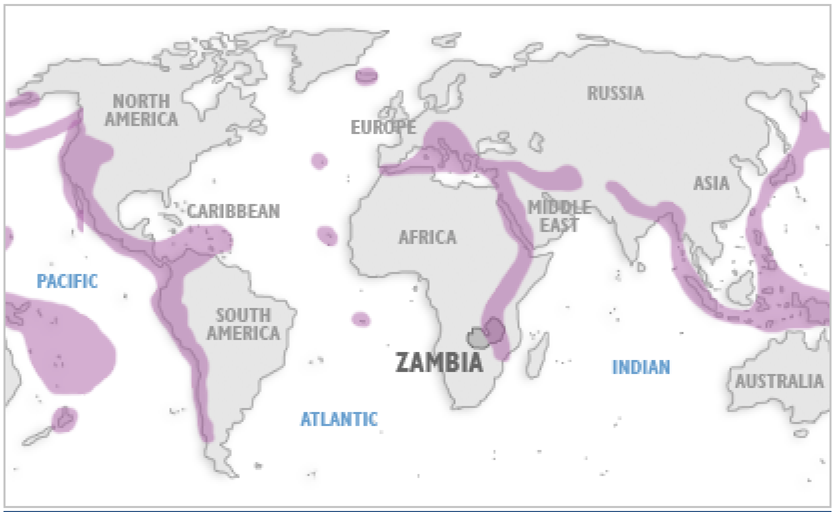


Figure 4 Hottest Known Geothermal Regions in the World [5]

LITERATURE SURVEY

One of the journals read was**:** *Optimal Sizing of Hybrid Ground-Source Heat Pump Systems That Use a Cooling Pond as a Supplemental Heat Rejecter— A System Simulation Approach Name*. The author's names were:

Mahadevan Ramamoorthy *Student Member ASHRAE*

Hui Jin *Student Member ASHRAE*

Andrew D. Chiasson *Associate Member ASHRAE*

Jeffrey D. Spitler, Ph.D., P.E *Member ASHRAE*

PROJECT OBJECTIVES

The hybrid geothermal heat pump will consist of several objectives. The first one is to assess the working state of the geothermal heat pump. It needs to be working properly in order to measure the efficiency of the heat pump (Coefficient of Performance), its Environmentally Efficient Ratio and how effectively it accommodates the FIU Solar House's cooling load. Once all the data has been acquired, further calculations will be performed to better understand the design of the air cooling tower that will be combined with the geothermal system. Due to the small size of the Solar House (755 square feet) a compact cooling tower should be designed. In implementing the cooling tower, the geothermal heat pump should reject heat with even more efficiency during extremely hot seasons such as the summer. Therefore, the cooling load will increase. Finally, it is important to implement a design that will work effectively, comply with the Department of Energy Safety Codes and Regulations and remain under budget.

CONCEPTUAL DESIGN

These two alternative designs will benefit geothermal heat pump to be more efficient by reducing heat, at the same time it will prevent any possible over heat situation and the pump will keep performing at its designed function. The first alternative design is to collect rain water into a container, these will help to cold down the geothermal pump the only problem of this design is that in South Florida, five-month of rainy season from June through October, when 70 percent of the year's rain falls, and the seven-month dry season from November through May [9], probably in those months from November to May there is no guarantee that it will be any rain. The second alternative design is to place a vent in the roof so it can absorb air from the outside and help to cool down the tubes so it can reduce the heat.

PROPOSED DESIGN

A small cooling tower will be incorporated into the geothermal heat pump system via the pump lines. As the hot refrigerant from the geothermal loops leave the condenser, it will enter a cooling tower. This cooling tower will use evaporation to remove the excess heat into the atmosphere. After cooling, the refrigerant lines will leave the cooling tower and enter again through the geothermal tubes to continue its cooling cycle. The cooling tower should be small because the FIU Solar House is small (only 755 square feet). However, the design should be the proper size to suit the year round hot weather in South Florida as well. It will be a compact system to be placed either on the ground next the house or on the roof. It will also comply with the Department of Energy (DOE) codes and regulations. The water cooling tower will also have a manual shut off-valve to close the line during the cooler seasons such as the fall and winter. This will allow the geothermal heat pump to work alone without the water cooling tower.

TIMELINE

Table 1 Time lime

	Spring				Fall				
Months	September	October	November	December	January	February	March	April	May
Definition									
Initation									
Planing									
Execution									
Equipment Research									
Choose Final Equipment									
Device assembly									
Device testing									
Solid Work									

Responsibilities

- Henry Gutierrez: CAD design, stress simulation, cooling tower efficiency calculations
- Miguel Freire: Manufacturing, material testing
- Santiago Paz: CAD design, fluid simulation, heat pump efficiency calculations

Table 2 Hours Spent

HOURS SPENT		
DATE	HOURS	ACTIVITIES
23-Aug-12	3	Searching a topic
27-Aug-12	3	Choosing a topic
28-Aug-12	4	Research of geothermal heat pump
30-Aug-12	2	Splitting responsibilities
4-Sep-12	5	Research geothermal heat pump
13-Sep-12	4	Working for team power point
18-Sep-12	2	Meeting with Dr. Lin
25-Sep-12	4	Reading and searching about geothermal heat pump
2-Oct-12	2	Meeting with Dr. Lin and visiting the Solar House
11-Sep-12	3	Working on the power point presentation for GL description
16-Oct-12	1	Meeting Dr. Lin
16-Oct-12	5	Project Synopsis
23-Oct-12	2	Softcopy team poster
30-Oct-12	4	Working on the Final report 10%
01-Nov-12	4	Working on the Final report 25%
06-Nov-12	1.5	Meeting with Dr. Lin
06-Nov-12	6	Working on the Final report 25%
Total	50.5	

In this chart represent at this moment for each team member the hours we spend since the beginning of the semester until this point.

Table 3 future hour spent

For next semester hour spent		
From 07-Nov-12 to 01-May-12	120	From buy the material, construction, testing, meeting with Dr. Lin

ANALYTICAL ANALYSIS

The analytical design involved using formulas that are related to air conditioning design, heat transfer concepts such as radiation and thermodynamics laws such as the First and Second Law.

The analysis of the cooling load from the solar house at FIU is described in detail. The first step was to make sure the geothermal heat pump was working. Once it started working, the total amount of heat transfer was calculated. This is crucial in knowing the full amount of heat rejected from the geothermal pump to the ground. Several considerations were taken into account. First, the solar house has an area of 755 square feet [16]which is usually the same dimensions of a one bedroom apartment. It is assumed that not more than three people will be living inside due to the space restrictions. Second, the total appliances for the FIU solar house are a refrigerator, microwave, three incandescent lights bulbs, and an electrical kitchen. There are some other appliances not taken into consideration due the small amount of heat transfer like two radios and one electrical watch. Third, temperature in Miami, for one year, was found in Figure 5. Every month was different ranging anywhere from roughly 58 degrees Fahrenheit to past 100 degrees Fahrenheit. Furthermore the properties of the material and the dimensions are listed in Table 16. The heat transfer from the outside to the inside is analyzed.

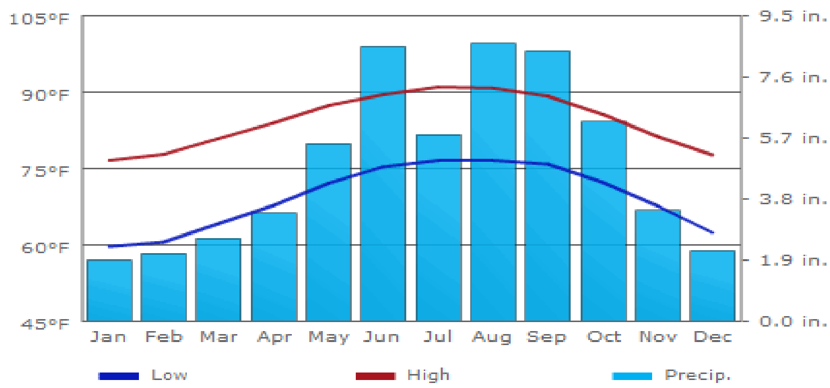


Figure 5 Miami Climate Graph - Florida Climate Chart

Heat rejection

Appliances

Refrigerator 15 Amps. 60 Hz. 120 V [26]

Microwave 20 Amps. 60 Hz. 120 V [27]

Electrical Kitchen 20 Amps. 60 Hz. 120 V [28]

Coefficient of performance

$$\beta = \frac{Q_L\,(\text{energy sought})}{W(\text{energy that costs})} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H / Q_L - 1}$$

Power (W)

$P = V * \mathrm{I}$

People rejecting heat

Three people at normal activities

139 W for each one [29]

qt = number of persons * Q

Incandescent light bulbs

Three incandescent lights

ql = 3.41 * W *Fu*Fs   (W)

q =heat gain BTU/hr

W = total installed light

Fu = use factor ratio

Fs= special allowance factor

Heat transfer from outside

$$\dot{Q}_s = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x}$$

Total heat transfer

$$q_t = q_n + q_p + q_l + q_o$$

MAJOR COMPONENETS

FHP Manufacturing designs the geothermal heat pump and the series of the heat pump is Aquarius II, Premier Series. The model number of the heat pump is AP 025 – 1VTC. The specifications regarding the heat pump are in Table 3. It is important to note that these specifications were found on the actual heat pump, located inside the FIU Solar House [14].

Table 4 Aquarius Geothermal Heat Pump Specifications

FHP Manufacturing								
Model: AP025-1VTC								
Serial Number: 3540-003-TW0001-T111M00012								
Unit Volts	208 - 230 V		**Phase**	1	**Frequency**	60 HZ	**Min Volts**	197 V
Compressor (EA)	208 - 230 V		**Rated Load Amps RLA (max current)**	11.4 A	**LRA**	52.0 A		
Blower MTR (EA)	208 - 230 V		**Full Load Amps FLA (motor running at 100% Capacity)**	2.80 A	Power	.33 Hp		
Loop Pump (OPT)	208 - 230 V		**FLA**	1.75 A	**Power**	1/6 Hp		
Minimum Circuit Amplicity	18.8 A							
Max Fuse	30							
Refrigerant	R410A							
Factory Charged Per Circuit	73 OZ							
Design Pressure	HI - 450 PSIG LO - 175 PSIG							

The RLA stands for rated load amps. The rated load amp is the maximum current that the compressor will use up during any “operating conditions” [12]. The LRA stands for Locked Rotor Amps and it depicts the current that the compressor will experience on initial startup [12]. It is important to note that during starting conditions, the voltage that the compressor will experience is a high one [12]. The FLA on the other hand stands for Full Load Amps and it has to do with the blower motor. In essence, the FLA refers to the blower motor’s capacity to turn the fan [13].

The refrigerant that the geothermal heat pump uses is R410A. A refrigerant is used to improve efficiency in HVAC systems such as heat pumps. R410-A is used because it is ozone friendly because it does not contain chlorine and therefore provides environmental benefit [15].

Another major component of the geothermal heat pump is the tubing laid out under the ground. The geothermal tubes are laid horizontally six feet under the ground as shown in Figure 16.

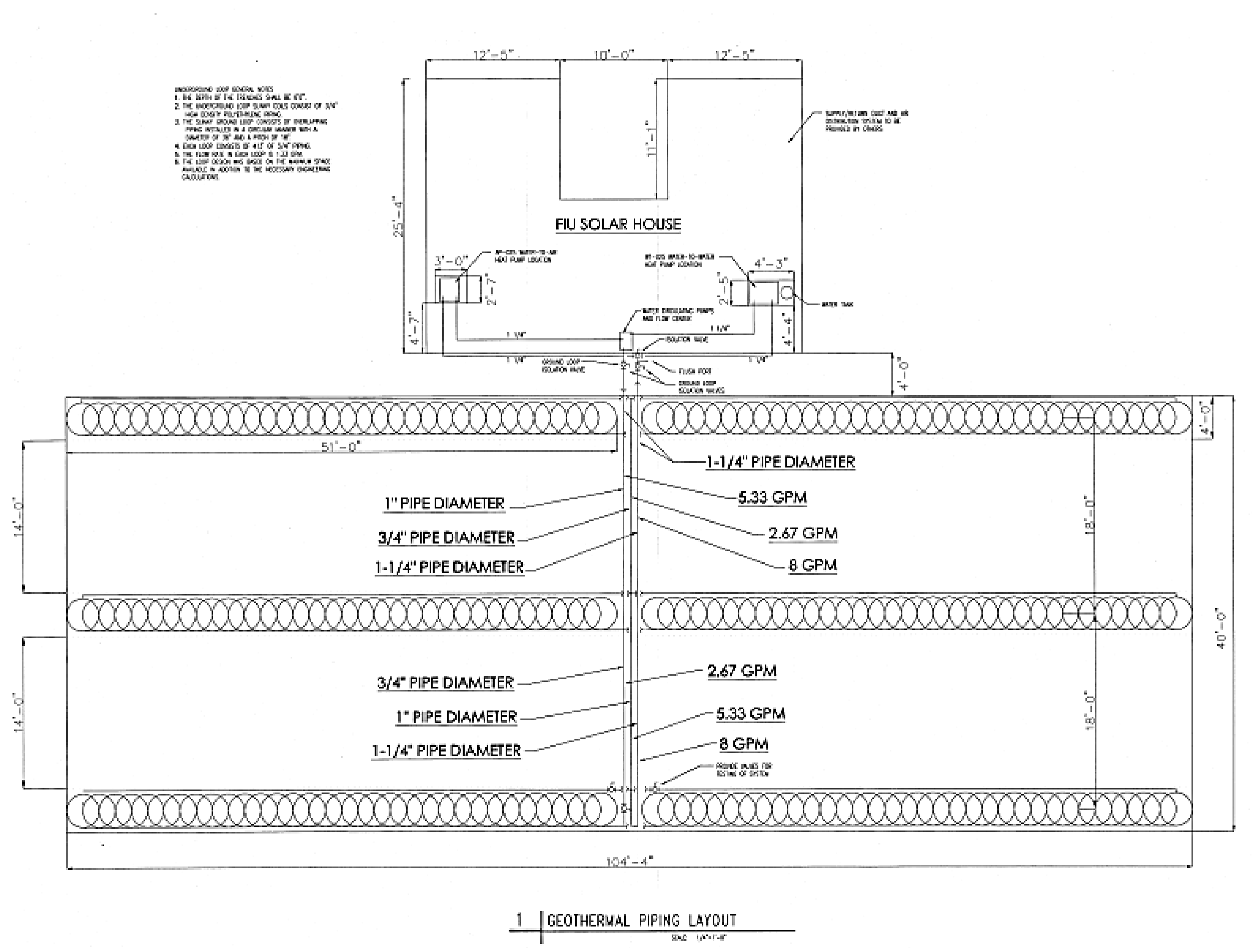


Figure 6 Geothermal Piping Layouts

The geothermal tubes were laid out horizontally for several reasons. The first is one is that it saves more money. Laying tube vertically means digging a deeper hole which costs much more money [17]. Furthermore, it is practical to use horizontal tubes for residential areas where there are no water wells nearby. A slinky method was used because amount of ground available was limited between the two parking spaces. Therefore the slinky method allows more pipe to be fitted in a shorter length trench [17].

The hybrid component is the next major component. The auxiliary heat rejecting system will be a cooling tower that will cool with an air fan. This air fan will consist of an outer case or frame, a fill, one or two nozzles and a fan. It will be directly connected with the geothermal heat pump in the following manner: after the refrigerant leaves the house, prior to entering the geothermal loop all over again, it gets cooled by the cooling tower.

STRUCTURAL DESIGN

The geothermal heat pump is already stationed in the FIU Solar House. However, in order to designs the auxiliary heat rejecting cooling tower several materials will be used. The frame of the cooling tower will made from galvanized steel or stainless steel to withstand corrosion from the environment [18]. The fill will be composed of plastic such as PVC or cheaper polymer [18]. The nozzle will also be made of PVC or ABS plastic [18]. For the fan aluminum or galvanized steel will be used depending on whether the fan will be centrifugal or propeller [18]. For example, centrifugal fans usually are manufactured from galvanized steel whereas propeller fans are made with galvanized steel, aluminum, or reinforced plastic [18]. These components are important because they will be chosen to "enhance corrosion resistance" and promote reliability, service and less maintenance [18].

COST ANALYSIS

Table 5 Cost Analysis

				Henry Gutierrez		Miguel Freire		Santiago Paz	
Task	Days	Man-Hours	Cost ($35/hr)	Percentage	Hours	Percentage	Hours	Percentage	Hours
Theoretical Research	55	60	$2,100	35%	20	25%	20	25%	20
Theoretical Analysis	35	50	$1,750	25%	16.66667	20%	16.66667	20%	16.66667
CFD and Simulation	30	70	$2,450	25%	23.33333	20%	23.33333	25%	23.33333
Prototyping	50	90	$3,150	25%	30	25%	30	25%	30
Testing	24	34	$1,190	25%	11.33333	25%	11.33333	25%	11.33333
Total	194	304	$10,640		101.3333		101.3333		101.3333

In this chart represent the man-hours with the cost and the percentage of each member of the group

PROTOTYPE CONSTRUCTION

PROTOTYPE SYSTEM DESIGN

Since the geothermal heat pump is already exist, the prototype will consist on building a Hybrid air cooling tower, these device will reject heat to the atmosphere, the goal is to balance out the annual load into the ground loop it will make the geothermal pump more efficiency, also by putting a shooting valve to the system that it will control when to turn on or off the cooling tower, only when its needed. [21]

PROTOTYPE COST ANALYSIS

For the prototype cost it will be designed to construct an air-cooling tower. The cooling tower will be residential also it will be small so it can be use in the FIU Solar House, the budged will be as low as possible to reduce cost from materials and ours spent. On the web page alibaba.com, for the material, the fan cost around $20-60 [22], Fill plastic pipe $6-10 [23], Nozzle $2 [24] and cooling tower frame $30-50 [25]

Figure 7 400mm fan

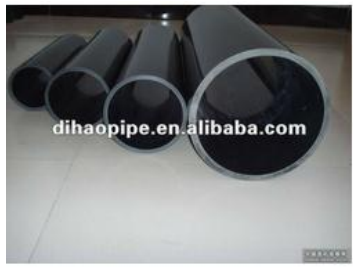


Figure 8 plastic pipes

Figure 9 stain steel nozzle

Figure 10 Cooling Tower Frame

PLAN FOR TEST ON PROTOTYPE

To test the air-cooling tower prototype it has to be connected to the geothermal heat pump by connecting them to the pipes to run some test to see if is worth it keep it or to do some modification.

CONCLUSION

Geothermal heat pumps work under the same principles as air conditioning systems. However, air conditioners themselves are better suited for the hot weather experienced in areas such as Southern Florida and Texas [1]. Heat pumps, on the other hand, by themselves, are well suited year round for “moderate climates” such as in the Mid-South and Tennessee [1]. Therefore, in order to accommodate to Miami’s hot weather, heat pump used in the FIU Solar House will consist of both geothermal energy and a water cooling tower. The combination of these two devices has increased the efficiency of removing excess heat during the summer.

Geothermal energy is used throughout the world and it is extremely efficient. In fact, according Tao, the annual saving of using a geothermal ground source heat pump compared to a conventional air source heat pump is 13.6% (8250 kWh versus 9550 kWh) [2]. For this reason, many countries around the world, especially those near the Pacific Rim, where the hottest geothermal regions are known use a lot of their energy from the ground [4]. Italy for example, provides 5200 GWh per year and Iceland provided 1500 GWh per year [3].

The water cooling tower will provide a higher level of efficiency because the gallons per minute of the refrigerants entering the loops will have enough time to cool before continuing the process. Other suggestions to be used in the future include the design alternatives specified. Furthermore, another kind of water cooling tower can be used.

REFERENCES

1. http://www.residential.carrier.com/knowledge/askme/heatpumporac.shtml

2. Yong Tao, "Analysis of Energy, Environmental and Life Cycle Cost Reduction Potential of Ground Source Heat Pump (GSHP) in Hot and Humid Climate," Proceedings of the U.S. Department of Energy, pp. 59, University of North Texas.

3. http://sanner-online.de/media/final$20paper$20country$20update$20overview.pdf

4. http://www.webmutations.com/energy/reports/present/repgeo.html

5. http://www.kalaharigeoenergy.com/geothermal_in_africa.htm

6. http://news.fiu.edu/2009/03/fiu-interior-design-goes-green/2837

7. Geothermal Piping Layout G-03

8. Geothermal Heat Pump Process

9. http://www.sfwmd.gov/portal/page/portal/levelthree/weather%20%20water

10. Ramamoorthy_Jin_Chiasson_Spitler_2001-Optimal sizing hybrid gshp using cooling pond.

11. http://blog.mechguru.com/machine-design/how-cooling-tower-works/

12. http://www.hvacrinfo.com/definitions.htm#rla

13. http://contractingbusiness.com/enewsletters/cb_imp_12085/

14. Aquarius Geothermal Heat Pump Specification. Own Picture, taken with cellphone camera. 2012 October 11.

15. http://www.lennox.com/beforeyoubuy/energy-efficiency/cooling-refrigerants.asp

16. Geothermal Piping Layout

17. http://energy.gov/energysaver/articles/geothermal-heat-pumps

18. United Nations Environment Programmer. Electrical Energy Equipment: Cooling Towers. Energy

19. Efficiency Guide for Industry in Asia, 2006. PDF file

20. AG_31-008_Geothermal_021607b.pdf

21. http://www.alibaba.com/product-gs/479206110/400mm_axial_fan.html

22. http://www.alibaba.com/product-gs/671209522/Large_diameter_Plastic_pipe_of_uhmwpe.html

23. http://www.alibaba.com/product-gs/440521235/stainless_spiral_cooling_tower_nozzle.html?s=p

24. http://www.alibaba.com/product-gs/544579545/Custom_Precison_Cooling_Tower_Frame.html

25. 30http://www.usclimatedata.com/climate.php?location=USFL0316

26. 31 http://www.kitchenaid.com/flash.cmd?/#/product/KSSC42QVS/

27. 32. http://www.kitchenaid.com/flash.cmd?/#/product/KHHC2090SSS/

28. 33. http://www.kitchenaid.com/flash.cmd?/#/product/KESS907XSP/

29. 34. Heating, Ventilation and Air Condition sixth edition Mc Quison Parker page 222

APPENDICES

Appendix A

Solar House Plans

A1 Geothermal Piping Layout

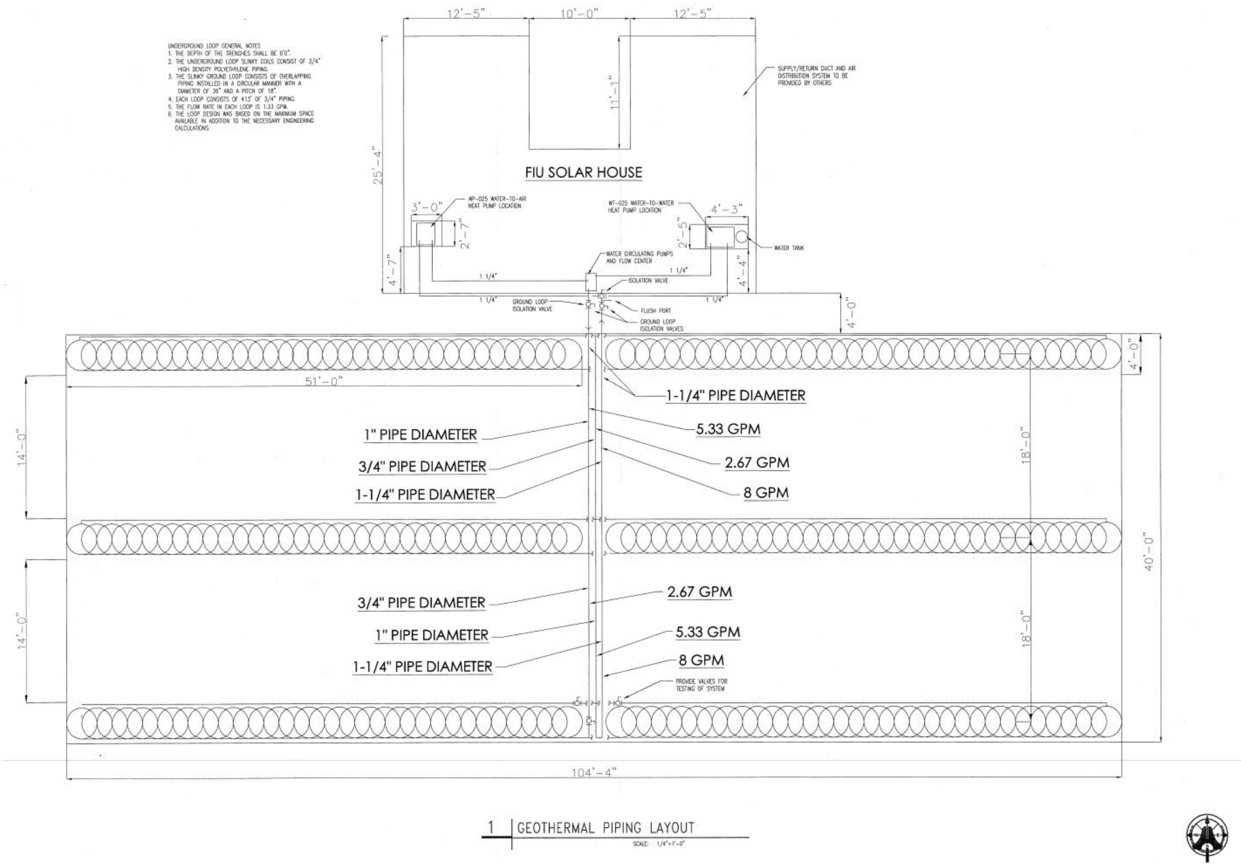
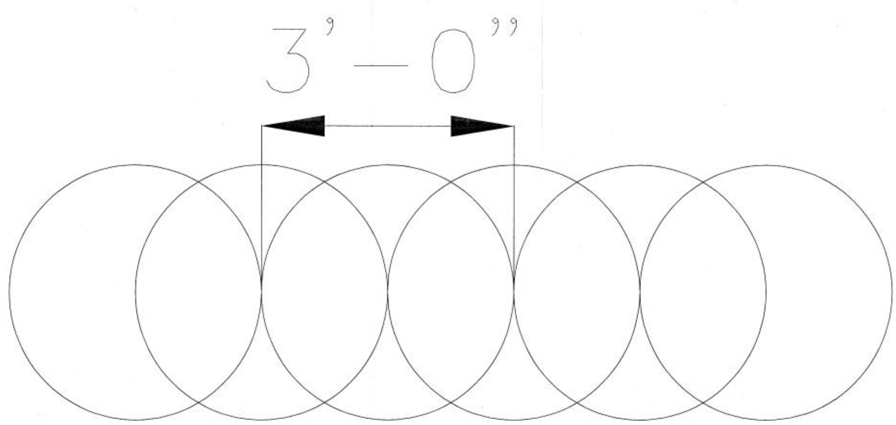


Figure 11 Geothermal Piping Layouts

A2 Ground Loop Cross Section

UNDERGROUND LOOP GENERAL NOTES

1. THE DEPTH OF THE TRENCHES SHALL BE 6'0".
2. THE UNDERGROUND LOOP SLINKY COILS CONSISTS OF 3/4" HIGH DENSITY HIGH DENSITY POLYETHYLENE PIPING.
3. THE SLINKY GROUND LOOP CONSISTS OF OVERLAPPING PIPING INSTALLED IN A CIRCULAR MANNER WITH A DIAMETER OF 36" AND A SPACING OF 18".



1 GROUND LOOP CROSS SECTION
SCALE: 1 1/2"=1'-0"

Figure 12 Ground Loop Cross Section