Efficiency and Performance Analysis of Geothermally Equipped Homes in New York State

Study conducted by:
Anthony Novakovic

Table of Contents

Acknowledgements

Mentors:

Lloyd Hamilton (February 2014 – July 2015)

Jefferson Tester (August 2015 – Present)

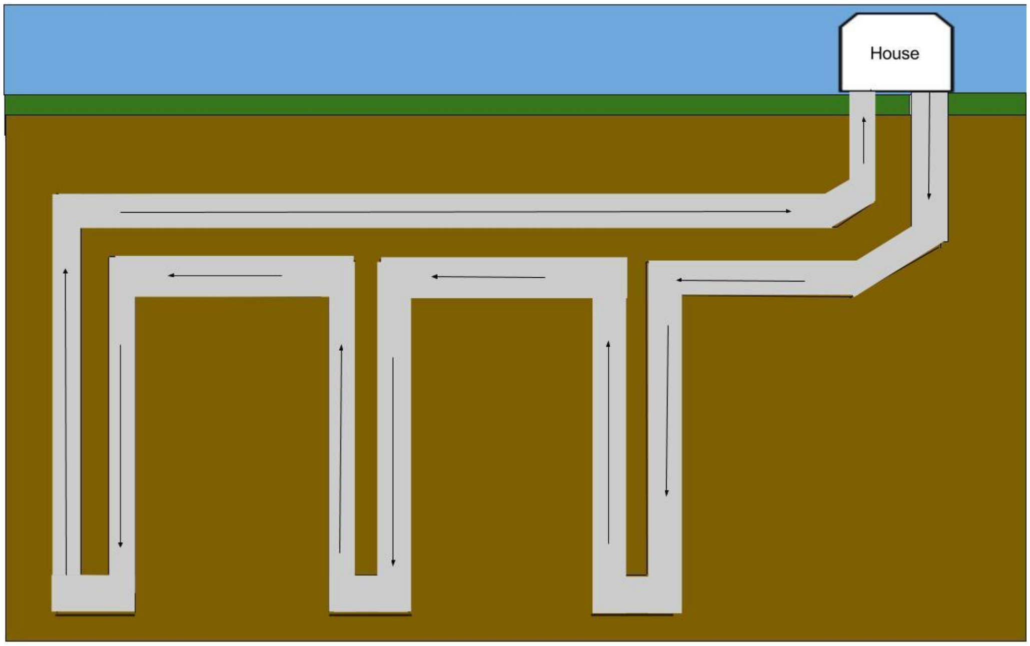
Instructors:

Michael Inglis (September 2013 – Present)

Review of Literature

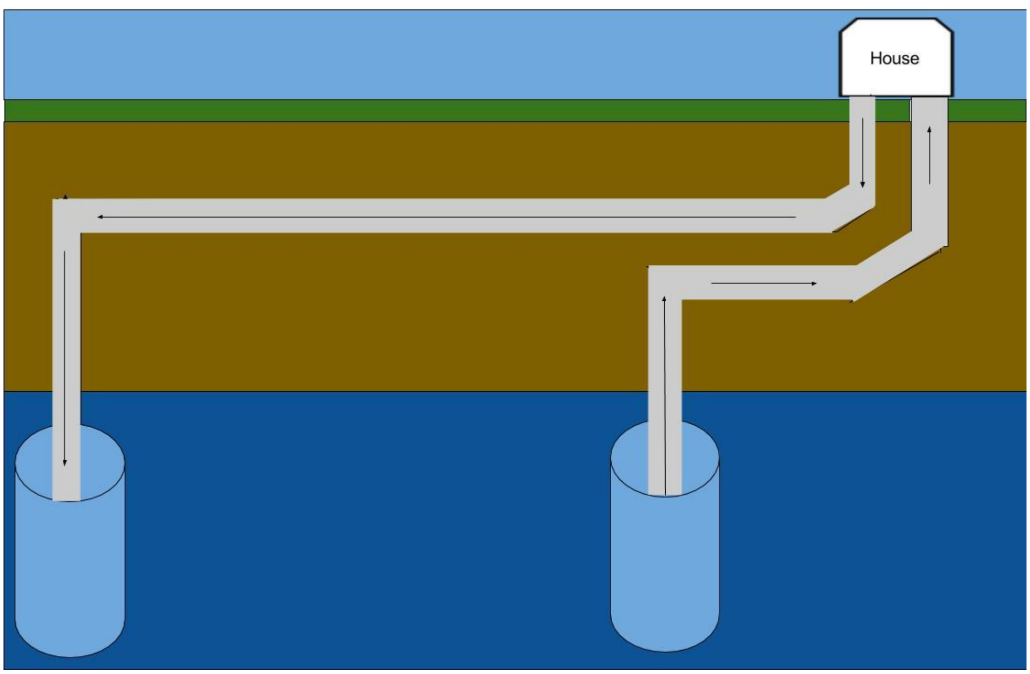
In recent years, awareness and demands for an alternative resource to eradicate fossil fuel usage have increased significantly. However, a "perfect" renewable alternative is nearly impossible; geothermal is the most suitable resource to meet the outrageously high energy expectations.

Geothermal energy can be found nearly anywhere within the earth's interior (Keçebas 2012). Throughout the year, the earth's lithosphere and crust maintain a constant temperature. As the sun heats the shallowest areas of the lithosphere, the inner core heats the deeper layers. Groundwater present in Earth's layers is naturally heated in the process (Hall et al 2011). The thermal energy within the groundwater (or sometimes steam) is crucial, as it opens many possibilities for residential, agricultural, and industrial heating. Wells are drilled through the Earth's layers to obtain water from these underground reservoirs (Keçebas 2012). However, the depths of these wells are dependent on the water's location and distance from the surface. The structures and properties of the wells are categorized into two types of systems that are known as open loops and closed loops. Closed loops are more frequently used and practical for heating purposes. Open loops are less popular because of requirements for a nearby water source (lake, pond, etc.) and normal pH levels, which are hard to find (Hall et al 2011). Groundwater can be directly utilized (open loop system) only when these conditions exist (Hähnlein et al 2013). Closed loops transfer groundwater's heat energy to a dedicated fluid via conduction. Particularly in closed loop systems, warm water is extracted from deeper well depths during winter months. During the summer months, colder water is extracted from shallower well depths (Hall et al 2011). Heat pumps extensively aid in the thermal extraction process by absorbing thermal energy from groundwater/dedicated fluid.



Closed Loop System

(Figure 1)



Open Loop System

(Figure 2)

Geothermal heat pumps are already a popular heating source in France, Germany, and Sweden. These countries also happen to have the highest national energy saving rates and ecological indexes (Arteconi et al. 2013). Heat pumps are very resourceful, as geothermal ground-source heat pumps have the largest energy use (68.3%) and installed capacity (47.2%) worldwide (Lund et al. 2011). It is especially desirable, when building heating needs alone consume over 80% of total energy consumption in most cold climate countries, and 25% of the total primary energy consumed in the United States (Morrone et al., 2014 ; Tester, 2011). In the United States, abandoned coal mines are large prospects in geothermal heating development (Hall et al 2014). The hot groundwater trapped within the mines has enormous potential to be utilized by local residential and industrial communities. Geothermal heating has been recently used for agricultural purposes (Keçebas 2012). In one study, a number of greenhouses in Europe were equipped with geothermal heating systems. The installation was a great success, with the geothermal systems significantly reducing heating costs and Green House Gas Emissions (Giambastiani et al. 2012). In recent years, geothermal energy has gained tremendous international recognition. Australia's government had funded $435 million for a Renewable Energy Demonstration Program. $153 million of the program had been used to aid two large-scale geothermal projects in Australia (Bahadori et al 2013). It is vital that countries seeking to exploit the full potential of geothermal energy follow in the footsteps of Australia's government and financially support geothermal growth.

However, performance and financial return from geothermal investments depend on efficiency. Efficiency heavily relies on the amount of energy implemented into the system, or the input. The paramount indicator when finding the efficiency of a geothermal system is the difference between the input and output. When the energy output is larger or the same as energy input, the system is efficient (Self et al 2011). A heat pump's efficiency is also characterized by the coefficient of performance (C.O.P.). The coefficient of performance is a ratio that represents heat pump efficiency. What defines a geothermal system as energy efficient are high C.O.P. ratios and system efficiency rates (Ozgener et al 2012).

While geothermal energy has been successfully implemented and used on a regular basis in various parts of the world, it is still developing in most places. The objective of this research is to analyze the performance of various geothermal systems across New York State, and indicate which system is the most energy efficient. This study will analyze the C.O.P. rates of six geothermal systems from October 1st 2014 to March 1st 2015.

Research Question/Hypothesis

In New York State, what type of geothermal system is most efficient when annually heating a suburban residence?

H_0: In New York State, it is inefficient to geothermally heat a suburban residence.

H_1: In New York State, it is more efficient to geothermally heat a suburban residence with a closed loop system than an open loop system, as the C.O.P. of a closed loop system meets or exceeds its expectations.

H_2: In New York State, it is more efficient to geothermally heat a suburban residence with an open loop system than a closed loop system, as the C.O.P. of an open loop system meets or exceeds its expectations.

Methods

Pre-data collection:

1. **Receive approval from mentor**:

In order to execute this study, my mentor, Lloyd Hamilton, must give consent to observe and collect data on the six geothermal systems in upstate New York. Sensitive information (client name, address, etc.) will not be revealed. Only the client's system data and well locations will be exposed. A codename will be assigned for each of the six systems.

2. **Identify the loop type for each client**:

All 4 systems are located in New York. Two of the total four clients being observed in this study have closed loop systems, and are located in New Paltz. The other two clients have open loop systems that utilize a primary ground loop with a drywell, and are located in Rhinebeck and Tivoli.

Loop Name	Loop Type
Alpha	Hybrid Open Loop/ Standing Column shown with primary ground loop including drywell. Tivoli, New York
Bravo	Hybrid Open Loop/ Standing Column shown with primary ground loop including drywell. Rhinebeck, New York
Charlie	Closed Loop System New Paltz, New York
Delta	Closed Loop System Closed Loop water to air New Paltz, New York

Figure 3

3. **Establish controlled variables**:

The six systems will have a constant value for water and antifreeze. Water will have a higher value (500) than antifreeze (475) because water is denser than antifreeze. Every system's performance data will be recorded and graphed over the course of twelve months. Periods of maintenance and inactivity will not be excluded from the data.

During experiment:

1. **Collect the data**:

Every fifteen minutes, each geothermal system wirelessly sends performance and diagnostic data to a server. This server is private and can only be accessed by people with the access code. The server facilitates the study, as it stores nearly 48 months of performance data. However, constantly checking the site to analyze well performances becomes an avoidable inconvenience. The data will be exported to Microsoft Excel, where it can be viewed and analyzed easier.

2. **Display the data**:

After the data is imported into Microsoft Excel, it can be properly analyzed and organized. Each geothermal system will be displayed individually with its performance data.

3. **Focus on specific variables**:

Out of all the variables available to study from the data sets, the most important variable to observe is the incoming water temperature for the geothermal system. For instance, a low incoming water temperature will most likely increase stress levels on the system, as it will take greater quantities of heat to meet the desired temperature. Ultimately, this will impact heat pump efficiency, Coefficient of Performance. The Coefficient of Performance (C.O.P.) is a ratio of heating/cooling provided by the heat pump to the total electrical consumption (Ozgener et al 2012). A high C.O.P. rate is an indicator that the system is highly efficient, as the energy output exceeds the energy input (.

4. **Search for any errors in the data set**:

When a geothermal system is turned on, the database collects C.O.P. rates that are impossible to achieve. Within the first three minutes, the C.O.P. will be recorded to be at “104” or “157”. These numbers are clearly inaccurate, as the expected C.O.P. for geothermal systems in upstate New York is around 4.0. (Tester). These errors in the data set will be identified and removed from the data appropriately.

5. **Compare monthly averages to expected C.O.P.**:

Once the monthly averages are completed for each system, they will be compared to the C.O.P. rates suggested for the heat exchanger. The suggested C.O.P. rates can vary among heat exchangers. To do a proper analysis, the heat exchanger manuals for each system were obtained. In the heat exchanger manuals, the expected C.O.P. is listed according to the system's incoming water temperature. The C.O.P. is based on the entering water temperature (EWT) of the system.

Loop Name	Heat Exchanger
Alpha	Climate Master Tranquility 27 Model 72 – Full Load
Bravo	Climate Master Tranquility 27 Model 49 – Part Load
Charlie	Water Furnace Envision Series NSW
Delta	Water Furnace Envision Series NSW

Figure 4

6. **Determine which system is the most efficient**

In this study, the system with a C.O.P. rating meeting or exceeding that of its heat exchanger will be considered the most efficient. This will be found using the deviation formula (Figure 5.)

$$\left(\frac{Measured\ Heat\ exchanger\ C.O.P. - Expected\ Heat\ Exchanger\ C.O.P.}{Expected\ Heat\ exchanger\ C.O.P.}\right) \times 100\%$$

Figure 5

Results

The data within the experiment was collected over the course of four months (November 1st 2014-March 1st 2015). Every ten seconds, data was sent electronically to a server, where it was recorded in the form of an excel spreadsheet. The data had to be manually extracted, as the website's performance abilities were limited. If the downloaded files exceed 1,000 kilobytes, the server would fail to load the data. To avoid website crashes, the 22 weeks of data was extracted in increments of five days (ex. 11/1/15 - 11/5/15).

When the data first reached Microsoft Excel, it had nearly 26,000 cells. When attempting to graph the cells into an X-Y line graph, Microsoft Excel crashed, as it had reached its maximum capacity. Soon after, the data had to be reorganized for proper analysis.

Instead of graphing the system every ten seconds, the system was only graphed when it was running and full operational. When the system was off, a numerical value of "1" appeared in the C.O.P. cell column. Cells with a numerical value of "1" were excluded from the graphed data. During this process, the chronological time order was not altered. While there were some time gaps between each system's on-off cycle, the data was not negatively altered. However, a line graph would no longer be the most suitable way to graph the data.

When the system would turn on, the database would prematurely calculate the C.O.P. to be nearly 150, which is thermodynamically impossible to achieve in these circumstances. To eliminate the possibility of getting false readings, the outlier data cells were extracted and the Y-axis was rescaled (0-15). However, the X-Y scatter plot turned out not to be reliable method when trying to interpret and conclude the datasets. The X-Y scatter plot did accurately reflect the system's C.O.P. rates, as outside air temperature (x axis) does not tremendously impact the system C.O.P. rates. Unlike outside temperature, ground temperature does not tremendously fluctuate, as the ground in Tivoli, Rhinebeck, and New Paltz remain around 50˚F throughout the winter (Gass, 1982).

Instead of analyzing the data through an X-Y scatterplot as originally planned, an alternative was taken, and the five-day data collections were organized into tables. These tables were organized by month, and contained four columns (Average Outside Temperature (F°), Average Water Input Temperature (F°), Average System C.O.P., and expected System C.O.P.).

Date:	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.
10/1 – 10/5	N/A	N/A	N/A	N/A
10/6 – 10/10	3.9748819	51.33	54.43	4.7
10/11 -10/15	4.0093644	54.25	53.27	4.6
10/16 -10/20	4.25219	41.54	53.73	4.6
10/21 – 10/25	4.1150	47.68	53.42	4.6
10/26 – 10/30	4.1990	45.81	53.49	4.6
10/31 – 11/4	4.1891	42.58	51.69	4.5
10/1 – 11/4	**4.12323**	**47.1983**	**53.34**	**4.6**

Bravo (Oct. 1 – Nov. 4)
[Figure 6]

The data from the four systems were organized in the same fashion. After the weekly averages were compiled into monthly tables, another table was created based solely off of the monthly averages collected throughout the season (10/1/14 – 3/1/15).

	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.	C.O.P. Deviation
Alpha	3.5865	47.7116	52.8134	3.65	-1.734%
Bravo	4.123256	47.1983	53.3383	4.2	-1.827%
Charlie	3.258263	47.176	51.9133	3.1	+5.105%
Delta	2.96588	14.5383	44.185	3.1	-4.326%

System Performances (10/1/14 – 11/4/14)
[Figure 7]

	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.	C.O.P. Deviation
Alpha	3.46125	34.4033	47.6783	3.5	-1.107%
Bravo	4.347008	34.7383	50.2983	4.5	-3.300%
Charlie	3.179962	35.333	50.2933	3.1	+2.579%
Delta	2.9450128	34.63	49.27	3.1	-5.000%

System Performances (11/5/14 – 12/4/14)
[Figure 8]

	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.	C.O.P. Deviation
Alpha	3.92	32.46	46.183	3.45	+13.623%
Bravo	4.421156	39.245	48.5933	4.4	+0.4808%
Charlie	3.470961	33.3683	49.1383	3.1	+11.967%
Delta	2.8578005	32.0316	47.365	3.1	-7.813%

System Performances (12/5/14 – 1/3/15)
[Figure 9]

	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.	C.O.P. Deviation
Alpha	4.09383	21.9666	44.846	3.4	+20.407%
Bravo	4.681535	26.7	46.3783	4.8	-2.468%
Charlie	3.315857	21.5666	47.6083	3.1	+6.964%
Delta	2.927769667	21.1066	45.3077	3.1	-5.556%

System Performances (1/4/15 – 2/2/15)
[Figure 10]

	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.	C.O.P. Deviation
Alpha	4.10683	18.2916	47.708	3.5	+17.338%
Bravo	4.432223	17.9732	45.21	4.2	+5.529%
Charlie	3.318633	15.8233	46.92	3.1	+7.053%
Delta	2.96588	14.5383	44.185	3.1	-4.326%

System Performances (2/3/15 – 3/1/15)
[Figure 11]

System	Average C.O.P.	Average Temp. (F°)	Average Water Temp. (F°)	Expected C.O.P.	C.O.P. Deviation
Alpha	3.83368	30.967	47.84574	3.5	+9.534%
Bravo	4.40103	33.171	48.76398	4.5	-2.199%
Charlie	3.30874	30.653	49.17464	3.1	+6.734%
Delta	2.93247	23.369	46.06254	3.1	-5.404%

System Performances (10/1/14 – 3/1/15)
[Figure 12]

After reviewing the data, it is evident that System Alpha has the greatest C.O.P. deviation amongst the four systems (as shown in Figure 12). However, System Alpha was not the top performer in other categories. While System Alpha exceeded its C.O.P. expectations by nearly. 9.5%, it did not have the highest C.O.P. rate compared to the three other systems. System Bravo did have a higher C.O.P. rate than System Alpha. However, the expected C.O.P. rate for System Bravo exceeded its actual performance, as System Bravo finished with a 4.40103 C.O.P. rate (2.199% below its expectations).

Out of the four systems, System Charlie was the only system to exceed its C.O.P. expectation throughout the whole season. While Alpha and Bravo both averaged a higher C.O.P. rating than Charlie, Alpha and Bravo both missed their C.O.P. expectations on at least two different occasions. It is difficult to claim that one system is definitely more efficient than another, as efficiency can be approached from different perspectives. System Charlie is efficient, as it performing at an above average, consistent, sustainable rate. However, in terms of C.O.P. rates, Alpha and Bravo (open loop systems) exceeded Charlie and Delta (closed loop systems).

While system Charlie did exceed C.O.P. expectations, it also had a higher incoming water temperature, which could have reduced the stress being placed on the system. The reduction of stress would ultimately influence higher productivity and result in better C.O.P. rates.

System Delta was not a strong candidate when it was compared to Systems Alpha, Bravo, and Charlie. While System Delta had an almost identical system setup as Charlie, it never once met or exceeded C.O.P. expectations throughout the year. It was the only system to average below a 3.0 C.O.P., which tremendously counters the performance of System Charlie.

The C.O.P. and incoming water temperature statistics taken from the data suggest that open loop systems are more efficient, as they provide higher average C.O.P. rates and meet or exceed their C.O.P. expectations. However, both systems have their advantages and disadvantages. While the open loop systems perform at a higher C.O.P. than closed loop systems, they at times do not meet or exceed their C.O.P. expectations.

Bibliography

Keçebaş, Ali. "Energetic, exergetic, economic and environmental evaluations of geothermal district heating systems: An application." Energy Conversion and Management 65. (2013): 546-556. ScienceDirect. Database. 20 Dec 2013. <http://dx.doi.org/10.1016/j.enconman.2012.07.021>.

Hall, Andrew, John Scott, and Helen Shang. "Geothermal energy recovery from underground mines." Renewable and Suitable Energy Reviews 15. (2011): 916-924. ScienceDirect. Database. 20 Dec 2013. <http://dx.doi.org/10.1016/j.rser.2010.11.007>.

Cassasso, Alessandro, and Rajandrea Sethi. "Efficiency of closed loop geothermal heat pumps: A sensitivity analysis." Renewable Energy 62. (2014): 737-746. ScienceDirect. Database. 20 Dec 2013. <http://www.sciencedirect.com/science/article/pii/S0960148113004217>.

Giambastiani, B.M.S., F. Tinti, D. Mendrinos, and M. Mastrocicco. "Energy performance strategies for the large scale introduction of geothermal energy in residential and industrial buildings: The GEO.POWER project." Energy Policy 65. (2014): 315-322. ScienceDirect. Database. 20 Dec 2013. <http://dx.doi.org/10.1016/j.enpol.2013.10.008>.

Bahadori, Alireza, Zendehboudi Sohrab, and Zahedi Gholamreza. "A review of geothermal energy resources in Australia: Current status and prospects." Renewable and Suitable Energy Reviews 21. (2013): 29-34. ScienceDirect. Database. 20 Dec 2013. <http://dx.doi.org/10.1016/j.rser.2012.12.020>.

Morrone, Biagio, Gaetano Coppola, and Vincenzo Raucci. "Energy and Economic Savings Using Geothermal Heat Pumps in Different Climates." ScienceDirect. Elsevier, 7 Aug. 2014. Web. 9 Sept. 2014.

Self, Stuart, Bale Reddy, and Marc Rosen. "Geothermal heat pump systems: Status review and comparison with other heating options." Applied Energy 101. (2011): 341-348 ScienceDirect. Database. 6 July 2011. Web. 30 October. 2014.

Ozgener, Leyla. "Coefficient of performance (COP) analysis of geothermal district heating systems (GDHSs): Salihi GDHS case study." Renewable and Suitable Energy Reviews 16. (2012): 1330-1334. ScienceDirect. Database. 24 Feb 2015.

Arteconi, A., N.J. Hewitt, and F. Polonara. "Domestic Demand-side Management (DSM): Role of Heat Pumps and Thermal Energy Storage (TES) Systems." *Thermal Engineering* (2013): 155-65. *ScienceDirect*. Web. 30 Oct. 2015. <http://www.sciencedirect.com/science/article/pii/S1359431112006357>.

Tester, Jefferson. "Lessons Learned from Energy Use in the U.S." Energy & Environmental Science 4.10 (2011): 3729-730. Royal Society of Chemistry. Web. 1 Nov. 2015. <http://pubs.rsc.org/en/content/articlelanding/2011/ee/c1ee01721g#!divCitation>.

Gass, T.E. "Geothermal Heat Pumps" Geothermal Resources Council Bulletin, 11 (1982): 3-8.