West Chester University
Digital Commons @ West Chester University

Student Work

Geology & Astronomy

2014

Assessing the Energy Efficiency and Emissions of a Vertical Closed-Loop Geothermal System at West Chester University

Jacqueline Wilson
West Chester University of Pennsylvania

Recommended Citation

Wilson, J. (2014). Assessing the Energy Efficiency and Emissions of a Vertical Closed-Loop Geothermal System at West Chester University. , 1-24. Retrieved from http://digitalcommons.wcupa.edu/geol_stuwork/2

Assessing the Energy Efficiency and Emissions of a Vertical Closed-Loop Geothermal System at West Chester University

Jacqueline Wilson, B.A, M.A.

Final Project submitted to the faculty of
West Chester University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS
In
Geoscience
Department of Geology & Astronomy

Dr. Martin Helmke, Committee Chair
Dr. Timothy Lutz
Dr. Howell Bosbyshell

West Chester, Pennsylvania

Assessing the Energy Efficiency and Emissions of a Vertical Closed-Loop Geothermal System at West Chester University

by

Jacqueline Wilson

ABSTRACT

This study explores the energy efficiency and emissions levels of the vertical closed-loop geothermal well system at West Chester University in southeastern Pennsylvania. Geothermal heating and cooling through the use of ground-source heat pumps relies largely on the storage of heat energy within the Earth. A closed-loop geothermal system utilizes wells typically between 100 and 500 ft. depth to exchange heat with the surrounding material, enabling the system to store heat underground for later use. The wells contain water which is pumped throughout the system to regulate temperature.

The Geothermal Initiative at West Chester University is a $40 million project currently under construction and consists of multiple well fields connected to a main pump house located on campus. Each well is approximately 500 ft. deep, located within a geologic region composed primarily of fractured gneiss. There will be a total of 1,400 wells installed by the project's completion, implemented in phases, that will power a majority of buildings on the university's North Campus.

To evaluate the efficiency of the system compared to traditional heating and cooling methods, temperature and electrical measurements were taken every five minutes from the main pump house between December 26, 2012 and December 5, 2013. Because the system is not completely self-sufficient, there is still an electricity demand to power the pumps that circulate

water throughout the buildings on campus. A total of 757,836 kWh of electricity was required for the heating component of the observed period, which would be the equivalent of 209,329 lbs of coal if this amount of energy was produced from the University's still-operational coal plant. For the cooling component of the system, there was a 47% increase in efficiency over the use of a traditional air conditioning system.

INTRODUCTION

West Chester University is located in southeastern Pennsylvania, approximately 25 miles west of Philadelphia. Recent efforts to reduce the University's carbon footprint led to the development of a Sustainability Council as well as the WCU Geothermal Initiative. Once completed, this $40 million project will supply a 16.1 MW heating/cooling demand to the campus of approximately 1,600 students.[1] The purpose of this Initiative is to greatly reduce the emissions of harmful greenhouse gases generated by the University.

Geothermal power is a clean, sustainable form of energy that uses a network of heat pumps connected to water-filled pipes and wells to transfer heat throughout a system. Traditional forms of geothermal power have been generated through the harnessing of natural geological features near the Earth's surface to produce steam power. However, the availability of these features is heavily dependent on geographical location and currently is only responsible for providing 0.3% of electricity generation in the United States.[1] For other locations, such as West Chester University, a different type of geothermal system is used. Ground-source heat pumps, also known as geo-exchange systems, effectively use near-surface geological material as a heat sink. This type of power can be used for both heating and cooling; heat can be taken out of a building and stored in the ground through the transfer of energy in a well field, where it can later be taken out of the ground and pumped throughout the system to provide us with heat when it is cold outside.

Geology plays an important role in geo-exchange systems. Mathematically speaking, heat flow through a geologic material is the same as groundwater flow. This allows existing groundwater modeling software to be used to predict the behavior of the stored heat from a geothermal system.[2] West Chester University is located in a region comprised predominantly of fractured Baltimore Gneiss, which has a low thermal conductivity and a high heat capacity compared to the geothermal heat flux of most other regions in the United States. In other words, the subsurface of this region is highly efficient at storing heat with minimal dissipation. For this reason, West Chester is a suitable location for a geo-exchange system and is expected to perform at a high rate of efficiency.

There are four basic designs for geothermal heat pump systems. Open-loop systems rely on a nearby body of water for thermal exchange, using water from a pond or lake to be pumped throughout its piping. The other three systems are variations of a closed-loop design. Like the open-loop system, a pond/lake system depends on a thermal exchange with a body of water. A pipe is run underground from a building and coiled into the water source. Horizontal-loop systems are typical for residential purposes, as they can be the most cost effective. Pipes are placed side-by-side in trenches dug next to the building, often looped in circles to maximize use of space. Lastly, vertical-loop systems are common for large-scale sites, as in the case of West Chester’s geothermal system, due to their minimal disruption of the surrounding landscape. Pipes are placed into holes at least 100 feet in depth, attached by horizontal pipes near the surface which are connected to the main pumps.[3]

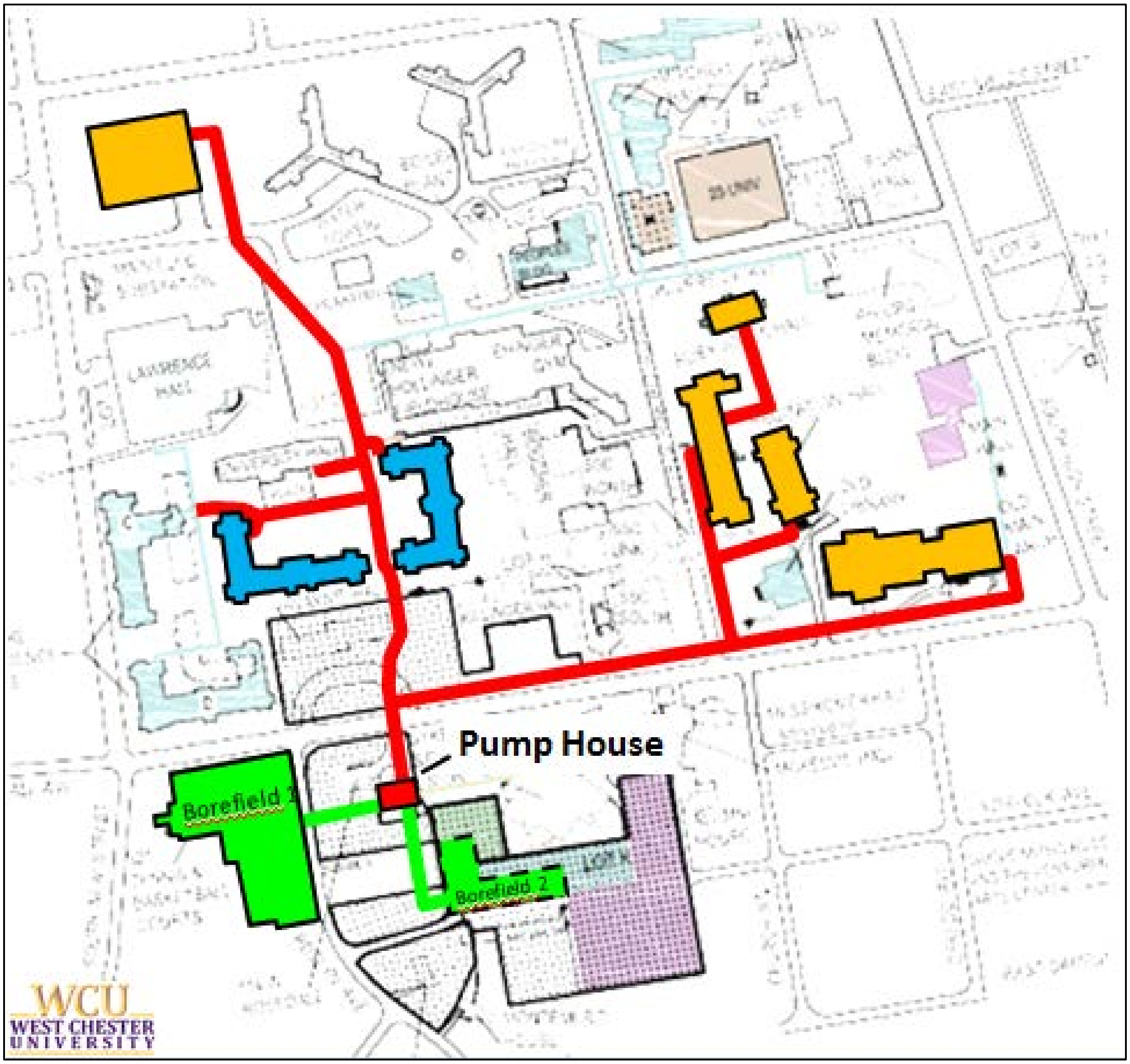


Figure 1. Map of West Chester University's geothermal system including Main Pump House, current well fields, and connected buildings.

Figure 1 shows the layout of West Chester University's geothermal system, with a central pump house relaying water from the well fields to the connected buildings on campus.[1] When construction is finished, 1,400 wells will provide power to a majority of the buildings on the university's North Campus. Each well is 500 feet in depth and is made of 1.25-inch PVC pipes. Monitoring wells are set up within each well field to allow for the tracking of both the water and ground temperature.

Emissions

There is a common misconception for the general public that geothermal systems produce clean, 100% emissions-free power. Unfortunately, this is not the case. While the heat energy stored in the ground through the well fields is “free” energy that comes from within the system, there is still an electrical demand for the pumps that power the system. For southeastern Pennsylvania, electrical power comes from a variety of sources including coal, nuclear, natural gas, and some renewable sources such as wind and solar power. Because of this, the geothermal system at West Chester University is still responsible for a certain amount of harmful emissions. Figure 2 illustrates the mix of electricity generation for the national averages compared to the southeastern Pennsylvania region which is powered by PECO, an Exelon corporation.[4]

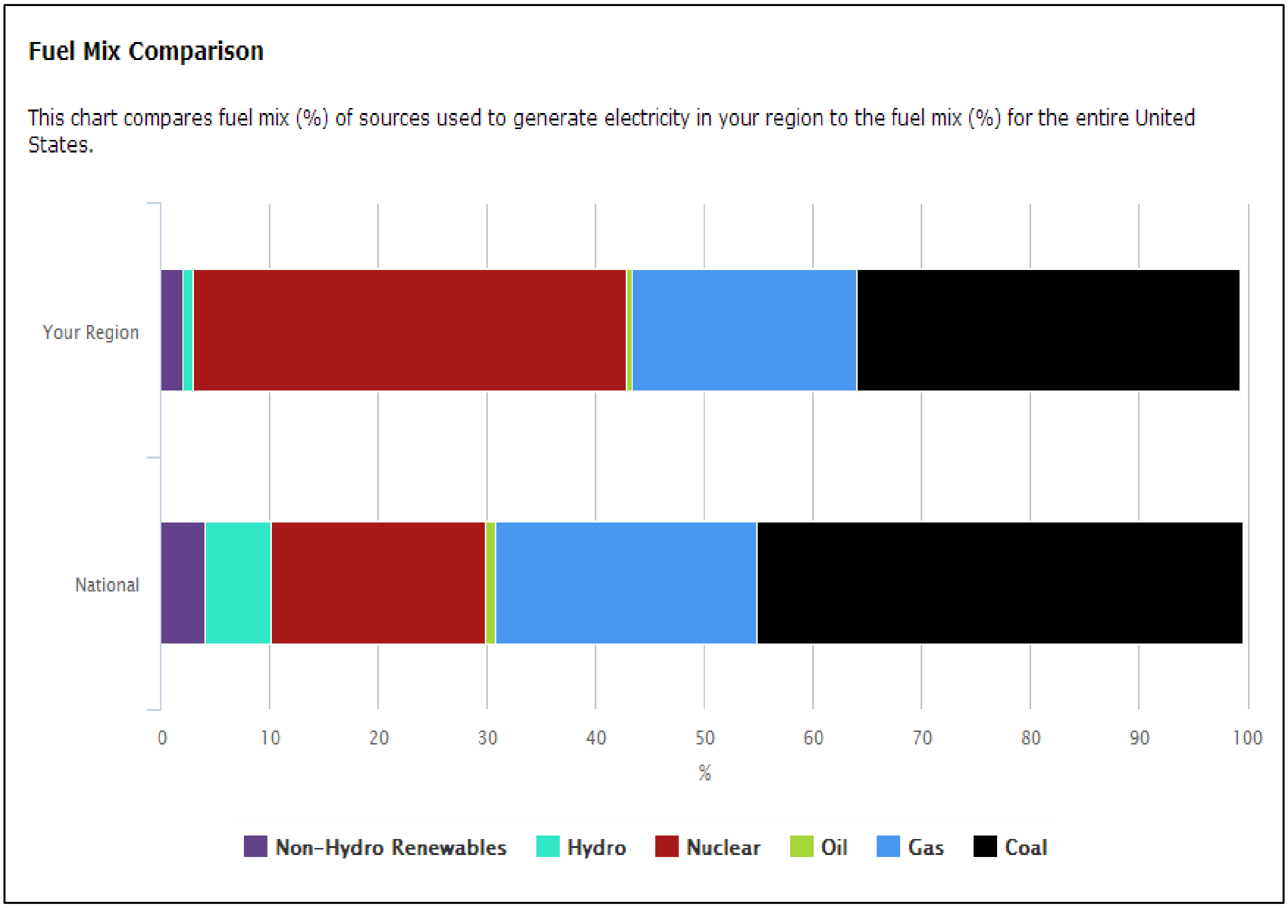


Figure 2. Power sources used to generated electricity for the southeastern Pennsylvania region.

Due to its proximity to both Limerick and Three Mile Island nuclear plants, nuclear power is currently the majority component of electricity generation for southeastern Pennsylvania at about 40%. While this region is historically known for its coal production and consumption, today coal generated power only accounts for about 35% of total electricity generation, which is well below the national average. West Chester University, however, currently maintains and operates its own coal plant that has served as the primary heating source for the campus until the geothermal system became operational in 2010. Reducing dependency on this facility is one of the main objectives for the Geothermal Initiative. From burning both coal and oil, the EPA estimates that the West Chester University coal plant emits 30 tons of particulate matter each year.[5] One goal of this study is to effectively calculate the reduction in harmful emissions the university for which the university would be responsible by switching the heating of campus from the coal plant to the new geothermal system.

System Efficiency

As noted above, a geothermal system requires electricity to power the heat pumps that drive the water between the piping in the well fields and the buildings on campus. In a typical geo-exchange system, one unit of energy from the electrical grid is required to provide the necessary power to retrieve 3-5 units of heat energy that has been stored within the ground. This results in a system that is ideally 400-600% efficient.[6]

The efficiency of the system heat pump is measured by a factor called the coefficient of performance, or COP_H. The COP_H is a useful piece of information when dealing with geothermal systems because it indicates whether or not the system is functioning at its maximum potential.

To calculate this number, the amount of heat being provided by the system (in watts) is divided by the electricity demand of the heat pump (also in watts), resulting in a unit-less factor. Figure 3 below displays the efficiency rates of a standard heat pump from ClimateMaster.[1]

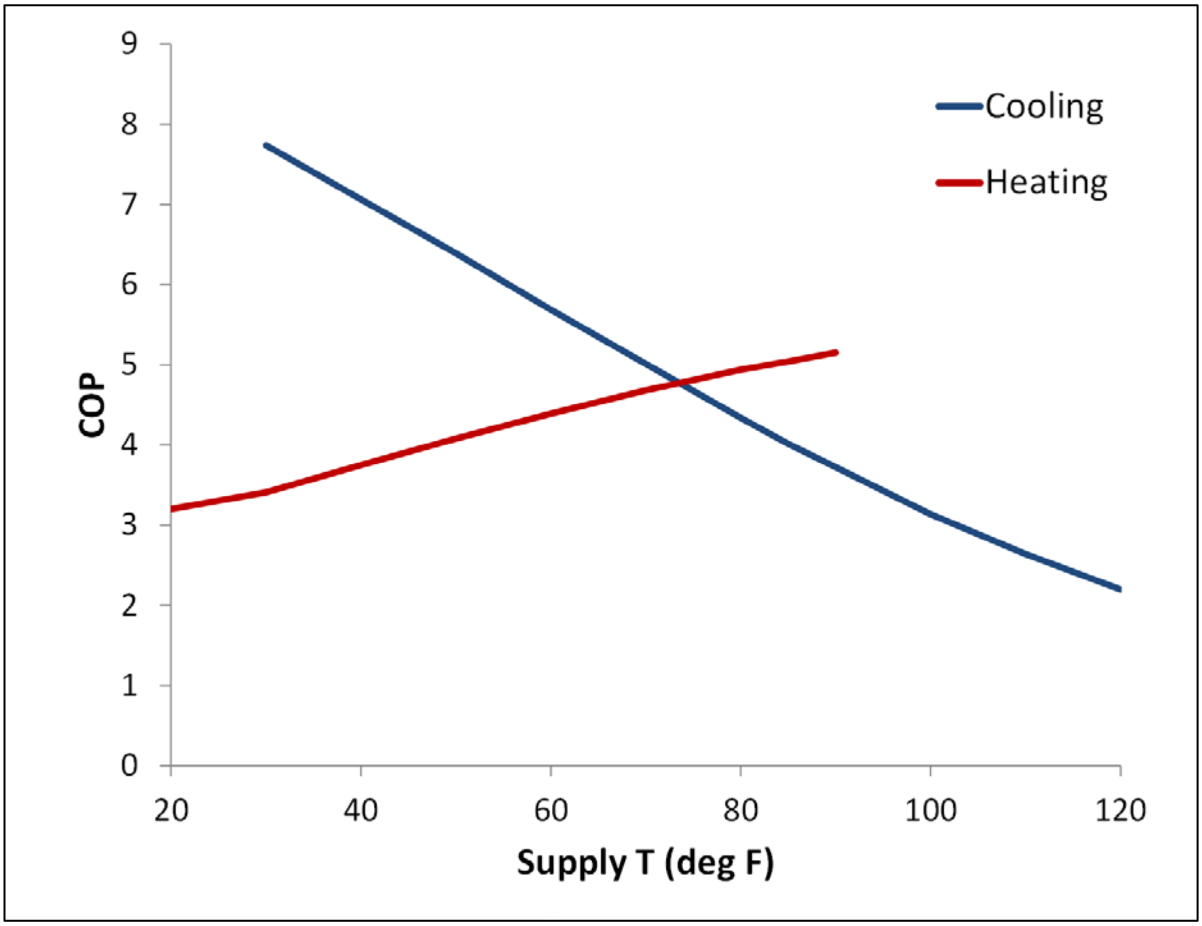
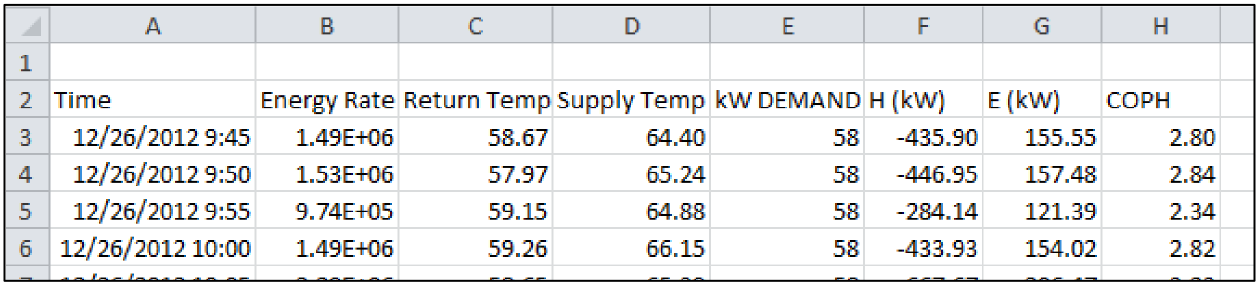


Figure 3. Coefficient of performance for a standard heat pump, based on heating or cooling.

As indicated by the graph, a heat pump is expected to perform at different levels of efficiency depending on whether the system is being cooled or heated. The supply temperature is representative of the temperature of the water coming from the well fields to be distributed throughout the rest of the system, after exchanging heat with the ground. When cooling, the system is the most efficient with a low supply temperature, and a pump will lose efficiency as the supply temperature increases. Conversely, when the system is heating, the efficiency of the heat pump has a direct correlation to the supply temperature. An older commercial air conditioning unit that would be used on a large scale such as for the buildings on a university campus, a COP_H of 2 is typical. However, the efficiency for heating campus buildings via the coal plant is not a factor because it does not function in the same manner; there is no electrical demand to power it, only coal and oil. Thus, for the purposes of this study, efficiency rates will be calculated primarily for the cooling season in order to compare the geothermal system's efficiency rate to that of a traditional air conditioning unit.

METHODS

To analyze the efficiency and the emissions of the geothermal system, data were collected between December 26, 2012 and December 6, 2013. This time frame allows for the observance of system performance throughout both the heating and cooling seasons. Measurements were taken at the main pump house on campus every five minutes to monitor electrical and temperature data, equating to 288 measurements each day. Figure 4 shows a portion of the resulting spreadsheet in Microsoft Excel.



	A	B	C	D	E	F	G	H
1								
2	Time	Energy Rate	Return Temp	Supply Temp	kW DEMAND	H (kW)	E (kW)	COPH
3	12/26/2012 9:45	1.49E+06	58.67	64.40	58	-435.90	155.55	2.80
4	12/26/2012 9:50	1.53E+06	57.97	65.24	58	-446.95	157.48	2.84
5	12/26/2012 9:55	9.74E+05	59.15	64.88	58	-284.14	121.39	2.34
6	12/26/2012 10:00	1.49E+06	59.26	66.15	58	-433.93	154.02	2.82

Figure 4. Sample of Microsoft Excel spreadsheet with resulting data from geothermal system measurements.

The energy rate in column B is measured in British Thermal Units (BTU). One BTU is the amount of heat energy required to increase the temperature of one pint (equivalent to one pound) of water by one degree Fahrenheit. Column C contains the temperature in Fahrenheit of the water returning from the buildings back into the well field, while column D has temperature information, also in Fahrenheit, for water being supplied to the rest of the campus system from the well field. If the supply temperature is warmer than the return temperature, it signifies that the system is heating the buildings on campus. This results in a negative value for column F, which converts the corresponding value in column B to kilowatt hours (kWh). One kWh is equivalent to 3.412.14 BTU. If the system is cooling, indicated by a warmer return temperature than supply temperature, the value in column F will be positive. Column E represents the electrical demand for the main pump house; however this value was not being measured until August 10, 2013. All values before that date are an average of the actual values that were taken for the remainder of the observed period. Column G is calculated based on the corresponding value for column F as well as the estimated COP_H of the system based on the line slopes for the chart in Figure 3. This value is different from the one in column E because it is representative of the electrical demand for the geothermal system as a whole, rather than just the pump house demand. Finally, the COP_H value is calculated from dividing the values in column F by the values in column G to get the average efficiency of the geothermal system for any given point in time.

After these numbers were calculated, the data for the energy generated by the geothermal system (column F) was partitioned into heating days and cooling days. A total amount of the heat energy supply (in kWh) was calculated for days in which the system was either heating buildings on campus during the observed time frame using the following equation (using heating days as an example):

H total (kWh) = [Average Daily H (kW)] x (24 hrs/day) x (Number of heating days)

A similar equation was used to find the electrical demands of the system (E total in kWh):

E total (kWh) = [Average Daily E (kW)] x (24 hrs/day) x (Number of heating days)

For the days in which the geothermal system was heating, emissions levels were calculated in order to be compared to the emissions of the coal plant. The three major forms of harmful emissions that are the focus of this study are carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrous oxide (NO_x). The regional energy profile for West Chester University lists the information for these three chemical compounds as stated in Figure 5:

Electricity Emissions Profile for Southeastern Pennsylvania	
1002	**Lbs. CO_2 per MWh**
2.1	**Lbs. SO_2 per MWh**
0.9	**Lbs. NO_x per MWh**

Figure 5. Harmful emissions factors for the southeastern Pennsylvania region. [4]

To find the emissions generated by the geothermal system, the total electrical demand of the system was converted to MWh and then multiplied by the corresponding emissions factors. Next, in order to compare emissions between the geothermal system and the coal plant, equivalent heating totals were calculated. Based on information directly from the coal plant on West Chester University's campus, each pound of coal that is consumed generates an average of 12,353 BTU of heat energy (D. Jones, personal communication, March 2014). The total heat power supplied by the geothermal system was used as a theoretical value for heat generation from the coal plant, converted into BTU, and then divided by the factor of 12,353 BTU/lb. to calculate the amount of coal that would be needed to supply the equivalent amount of heat energy. That coal value, in pounds, was then converted into emissions totals by the factors for standard bituminous coal as listed in Figure 6. It is worth noting that the value for carbon dioxide emissions is based from a coal plant designed to generate heat only, as opposed to a coal plant designed to generate electricity.[7] Electricity-producing coal plants are much less efficient, which would result in a dramatically higher emissions factor.

Emissions Factors for Bituminous Coal	
205.3	**Lbs. CO_2 per million BTU**
0.908	**Lbs. SO_2 per million BTU**
0.422	**Lbs. NO_x per million BTU**

Figure 6. Bituminous coal emissions factors. SO_2 and NO_x emissions factors were provided directly from the WCU coal plant.

Once the emissions were found for both the actual geothermal emissions and the theoretical coal plant equivalent, the totals for each heating method were compared for CO_2, SO_2, and NO_x.

The West Chester University coal plant also provided data pertaining to total amounts of coal fired during the 2013-2014 winter season. While two of the five boilers at the plant operate on oil, only the three coal-powered boilers were evaluated for the purposes of this project. At the time of correspondence, full monthly totals were provided from October 2013 through February

2014. Using a similar method as described above, actual emissions from the coal plant were calculated, and then theoretical emissions for the geothermal system were found using the equivalent heating values. In both of these scenarios, a final calculation was completed to find the percent reduction in emissions from using the geothermal system, as opposed to the coal plant, for heating the West Chester University campus:

$$\textbf{\% Reduction in Emissions} = \frac{\textbf{(Coal Plant Emissions)} - \textbf{(Geothermal Emissions)}}{\textbf{Coal Plant Emissions}} \times \textbf{100}$$

For evaluating the efficiency of the geothermal system, a COP_H value was found for both the heating and cooling days using the efficiency equation below (using cooling as an example):

$$\boxed{COP_H = \frac{\text{Average Daily H (kW)}}{\text{Average Daily E (kW)}}}$$

The COP_H for the cooling component of the geothermal system was then compared to that of a traditional commercial air conditioning unit, given a standard COP_H of 2 (M. Helmke, personal communication, April 2014). A percent increase in efficiency of system cooling was then found using the following equation:

$$\textbf{\% Increase in Cooling Efficiency} = \frac{|(\text{“Old A/C” } COP_H) - (\text{Geothermal } COP_H)|}{\text{“Old A/C” } COP_H} \times 100$$

RESULTS/DISCUSSION

As noted above, each day for the observed time frame for this study had measurements taken every 5 minutes, for a total of 288 data points per day. Upon review of the initial data collection, it was noted that several days in the observed time frame were missing a portion of the expected measurements. With limited access to the pump house, it can be challenging to determine the causes of these disruptions. However, there was no discernable pattern detected for the days with missing information. Possible explanations could include the pump house going offline for various maintenance reasons, or missing/extra data points due to Daylight Savings Time adjustments. The chart in Figure 7 below indicates the percentage of data missing for any given day in the observed period:

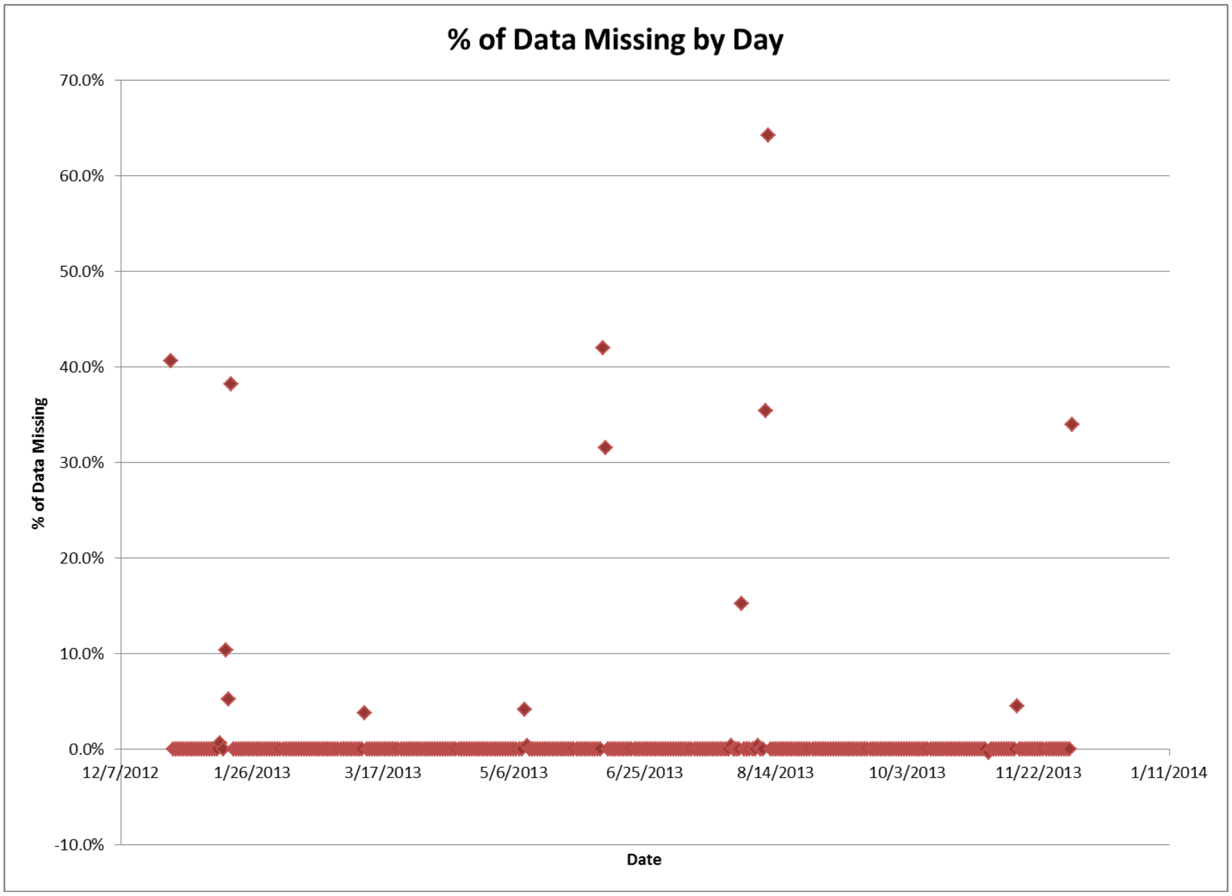


Figure 7. Percentage of geothermal data missing by day for observed time period.

Due to the variance in temperature and heat demand throughout the course of a day, missing data could possibly skew the daily average results depending on what time of day no data was reported. For example, if nighttime low temperatures were not recorded for a date in midwinter, the values could appear warmer overall than they actually were and thus would result in a seemingly less efficient system. The reverse could also be true; missing daily high temperatures for the same time of year would skew the data in the opposite direction, making the system appear more efficient. However, the relatively small and erratically-spaced number of days with missing data compared to the observed period as a whole will likely result in negligible variances in the calculated results.

Emissions

For the total heat energy supplied and electrical demand from the geothermal system in observed period, the following values in Figure 8 were calculated:

Heating

H (kW)	E (kW)	COP_H	nHeatingDays	H total (kWh)	E total (kWh)
234	102	2.29	135	757,836	331,503

Cooling

H (kW)	E (kW)	COP_H	nCoolingDays	H total (kWh)	E total (kWh)
560	190	2.94	210	2,821,708	958,551

Figure 8. Total amounts for geothermal energy heat supply and electrical demand.

To compare the actual emissions from the heating days of the geothermal system with theoretical emissions from the coal plant for the equivalent heat energy production, the H total for heating days (757,836 kWh) was multiplied by the emissions factors in Figures 6 to find the actual emissions for the geothermal system. The same H total was converted into BTU and then divided by the coal plant's conversion rate of 12,353 BTU/lb. of coal consumption, resulting in 209,329 lbs. of coal needed to generate the equivalent amount of heat energy. This number was then converted into emissions totals using the emissions factors from Figure 5. The calculations in Figure 9 below represent the harmful emissions totals, in pounds:

Emissions (in lbs.) for 757,836 kWh:

	Geothermal	**Coal Plant**
CO_2	332,166	530,874
SO_2	696	2,348
NO_x	298	1,091

Figure 9. Emissions totals for actual geothermal heat supply vs. theoretical coal plant equivalent.

After the values from the energy usage of the geothermal system were found, the totals from the Coal Plant heat generation between October 2013 and February 2014 were calculated. Figure 10 on the following page shows the totals of coal fired in pounds, corresponding heat energy generated in BTU, and then calculated emissions, in pounds, based on the emissions factors from Figure 6.

Next, theoretical values for an equivalent amount of heat generation from the geothermal system were calculated. Figure 11 on the following page shows, once again, the total of coal fired by the Coal Plant, in pounds, between October 2013 and February 2014. For this scenario, the energy generation was converted into MWh to allow for the calculation of the electrical demand based on the COP_H determined for system heating in Figure 8. This allowed for the emissions totals, in pounds, to be calculated based on the emissions factors from Figure 5.

Actual Emissions (in lbs.) from Coal Plant (October 2013 - February 2014)

Coal Fired by Month (lbs.)		BTU Generated	CO_2 Emissions	SO_2 Emissions	NO_x Emissions
October	380,667	4,702,379,451	965,399	4,270	1,984
November	904,334	11,171,237,902	2,293,455	10,143	4,714
December	958,610	11,841,709,330	2,431,103	10,752	4,997
January	1,539,036	19,011,711,708	3,903,104	17,263	8,023
February	1,296,558	16,016,380,974	3,288,163	14,543	6,759
Total	**5,079,205**	**62,743,419,365**	**12,881,224**	**56,971**	**26,478**

Figure 10. Coal Plant usage (in lbs.), energy generation (in BTU), and emissions (in lbs.) between October 2013 and February 2014.

Theoretical Emissions (in lbs.) from Geothermal System Equivalent to WCU Coal Plant Heat Production (October 2013 - February 2014)

Coal Plant Totals per month (lbs.)		MWh Generated	E demand (MWh)	CO_2 Emissions	SO_2 Emissions	NO_x Emissions
October	380,667	1,378	603	604,047	1,266	543
November	904,334	3,274	1,432	1,435,008	3,008	1,289
December	958,610	3,470	1,518	1,521,133	3,188	1,366
January	1,539,036	5,572	2,437	2,442,160	5,118	2,194
February	1,296,558	4,694	2,053	2,057,393	4,312	1,848
Total	**5,079,205**	**18,388**	**8,044**	**8,059,741**	**16,892**	**7,239**

Figure 11. Theoretical emissions for geothermal system based on equivalent coal consumption. Includes coal plant usage (in lbs.), heat energy generated (in MWh), and theoretical electricity demand (in MWh).

A total of more than 5 million lbs. of coal was consumed at the West Chester University coal plant between October 2013 and February 2014. As seen by the results from Figure 10, approximately 12.9 million lbs. of CO_2 were released into the atmosphere. If the geothermal system on campus had been used for that amount of heating instead, only about 8 million lbs. of CO_2 would have been emitted. The chart in Figure 12 illustrates this difference in emissions totals for CO_2:

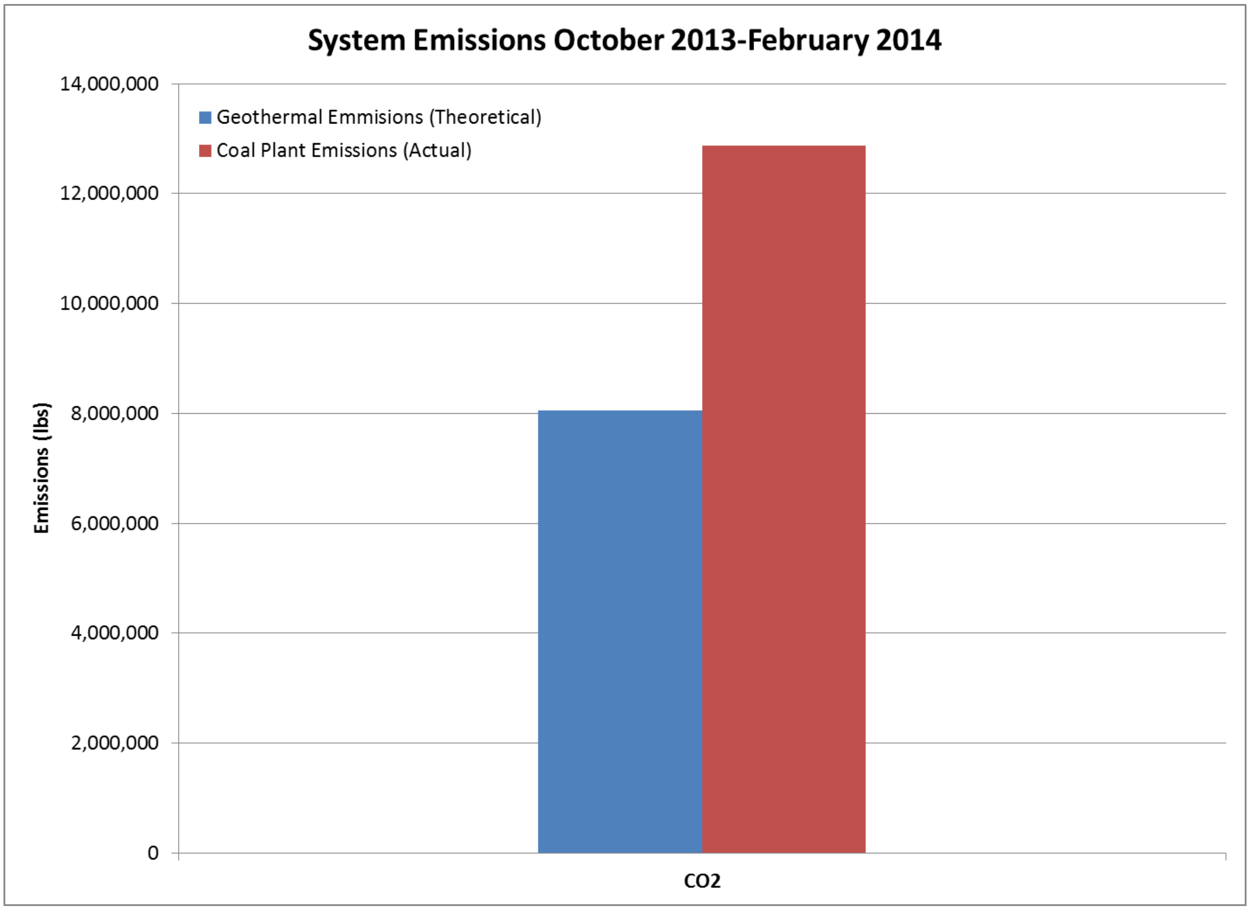


Figure 12. Difference in carbon dioxide emissions based on actual coal plant emissions and theoretical geothermal system emissions for equivalent heat production values.

In addition to saving on coal consumption expenses, the university would have saved more than 4.8 million lbs. of CO_2 from being emitted into the atmosphere if the geothermal system would have been used for heating the portion of campus that was heated by coal between October 2013 and February 2014.

If geothermal heating had been used for that portion of campus, the university also would have greatly reduced the amount of SO_2 and NO_x emissions for the same time period. Based on the coal plant's measurements, a total of 56,971 lbs. of SO_2 and 26,478 lbs. of NO_x were emitted between October 2013 and February 2014. However, the equivalent amount of geothermal heating would only have been responsible for 16,892 lbs. of SO_2 and 7, 239 lbs. of NO_x. These totals can be compared in Figure 13:

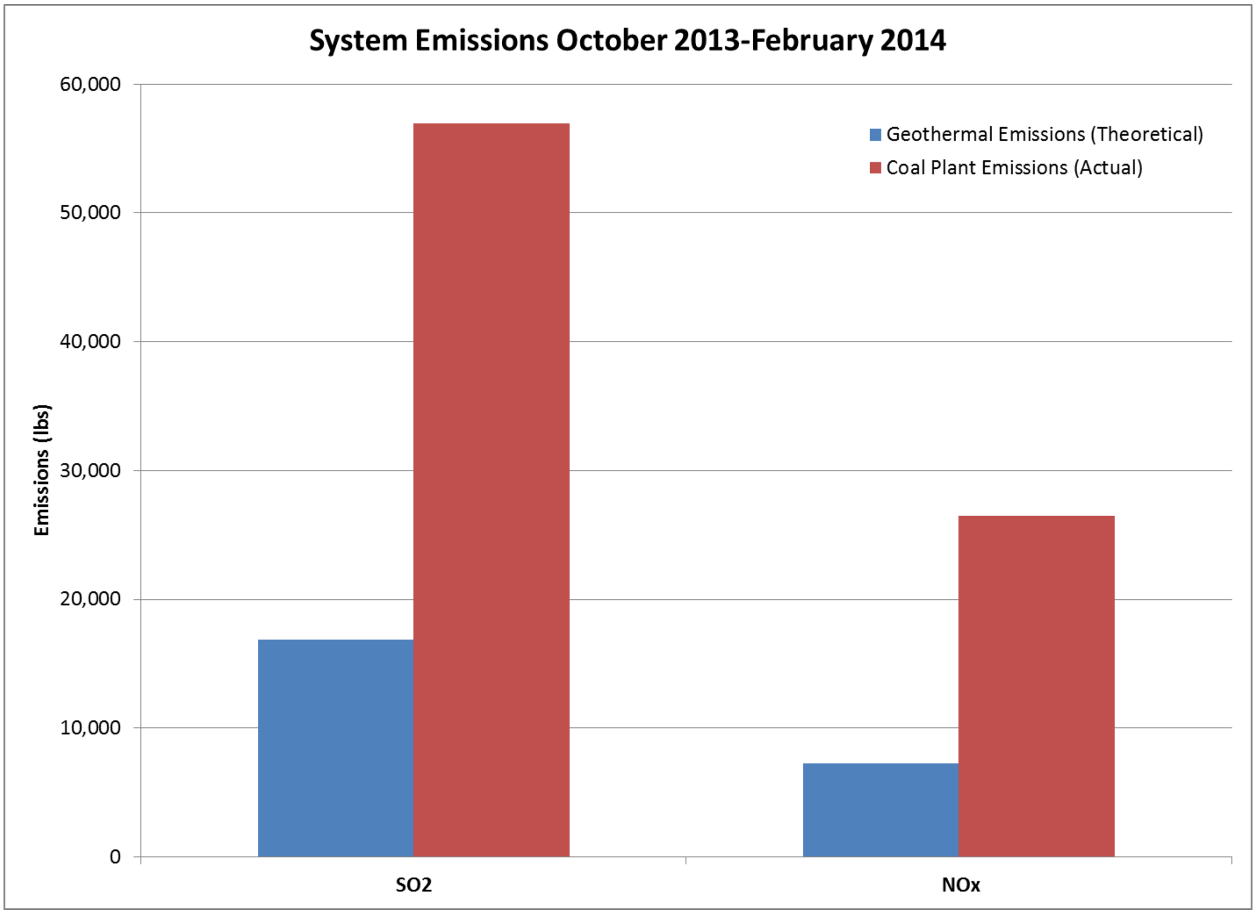


Figure 13. Difference in sulfur dioxide and nitrous oxide emissions based on actual coal plant emissions and theoretical geothermal system emissions for equivalent heat production values.

Even though the overall emissions totals for these two chemical compounds is significantly less than that of CO_2, there would have been a much larger decrease in these harmful gases if the geothermal system had been used for this amount of heat generation as opposed to the coal plant. Figure 14 below shows the percentage reduction in all three emissions between the actual coal plant emissions and the theoretical geothermal system emissions:

Reduction in Emissions from heating:

CO_2	37.43%
SO_2	70.35%
NO_x	72.66%

Figure 14. Percent decrease in emissions after switching from coal plant heating to geothermal heating.

As shown, there would have been a 37.43% decrease in CO_2 emissions after switching from the coal plant to the geothermal system for heating. SO_2 and NO_x, however, were reduced by dramatically higher rates of 70.35% and 72.66%, respectively.

System Efficiency

As shown in Figure 8 above, the geothermal system's average COP_H was found to be 2.29 for days when it was heating campus buildings, and for days in which it was cooling them, the COP_H was found to be an average value of 2.94. Because the heating of campus via the coal plant is not measured using a coefficient of performance, the geothermal system efficiency was compared primarily for the summer months during which the campus buildings required cooling, against a COP_H of 2 for a traditional commercial air conditioning unit. To calculate the percent increase in efficiency of the geothermal compared to the older A/C units, the following equation was performed:

$$\textbf{\% Increase in Cooling Efficiency} = \frac{|2 - 2.94|}{2} \times 100 = 47\%$$

By switching to geothermal power for cooling campus, there was an average increase of 47% efficiency of system performance. However, this value is not fully representative of the complexity of system performance for the geothermal heating and cooling. Figure 15 shows the daily values of heat supply (in kW), electrical demand (in kW), and corresponding COP_H values:

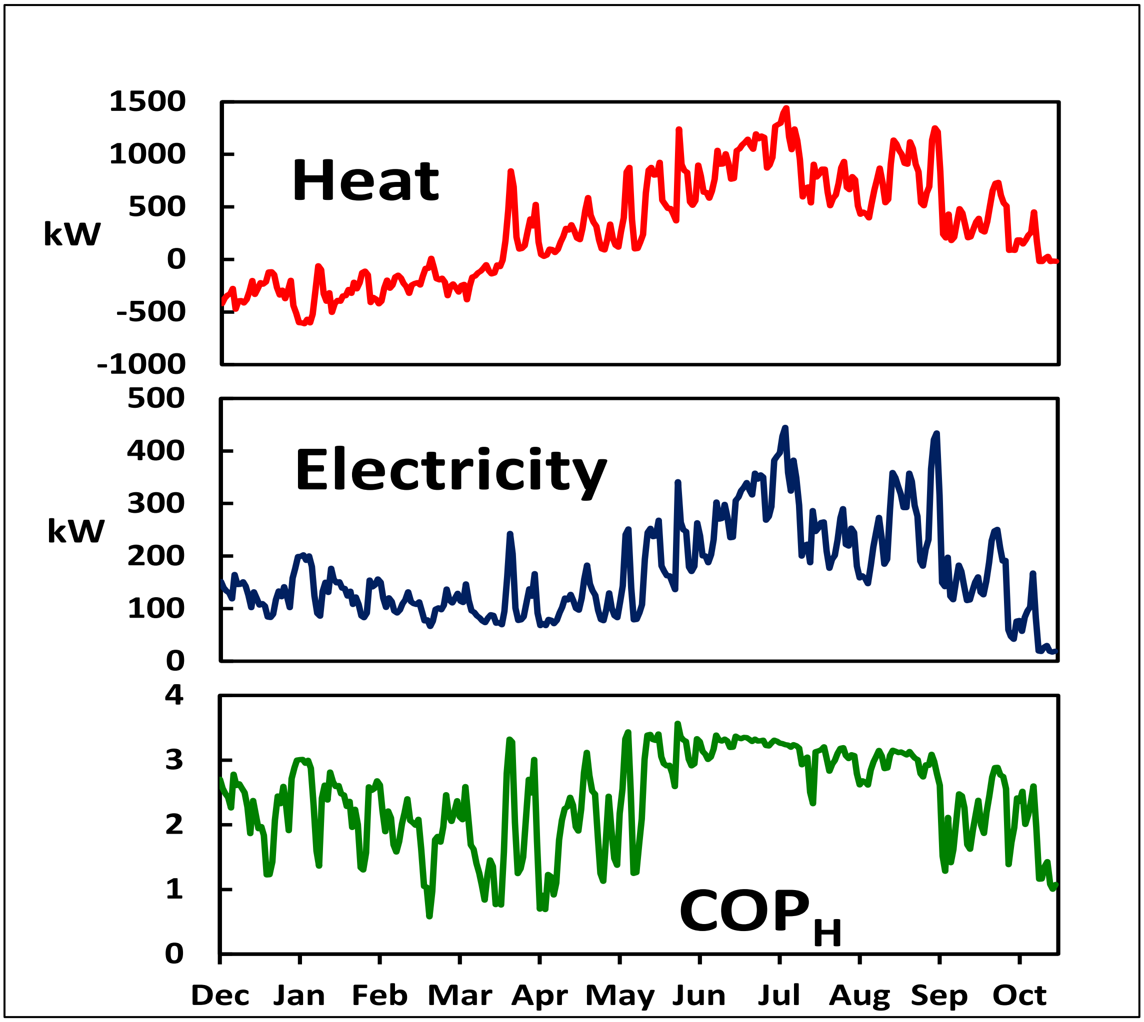


Figure 15. Daily values for geothermal system heat generation (kW), electricity demand (kW), and resulting coefficient of performance.

As shown, heat supply and electricity demand of the geothermal system are closely linked, however throughout the course of a year the COP_H of the system will vary significantly. It is clear that the geothermal system is the most efficient in the summer months when the buildings on campus are being cooled, with the lowest trend in efficiency during the spring and fall months. To consider the reasoning for these time spans of lower efficiency, the time of year is important to consider. In the months where outside air temperatures are mild, heating and cooling systems logically are used less and therefore do not perform to their maximum efficiency potential. For the observed time period of this study, average daily outdoor air temperatures were recorded and then compared to the daily average COP_H values for the geothermal system. Figure 16 clearly indicates a trend in system performance with respect to outdoor air temperatures.

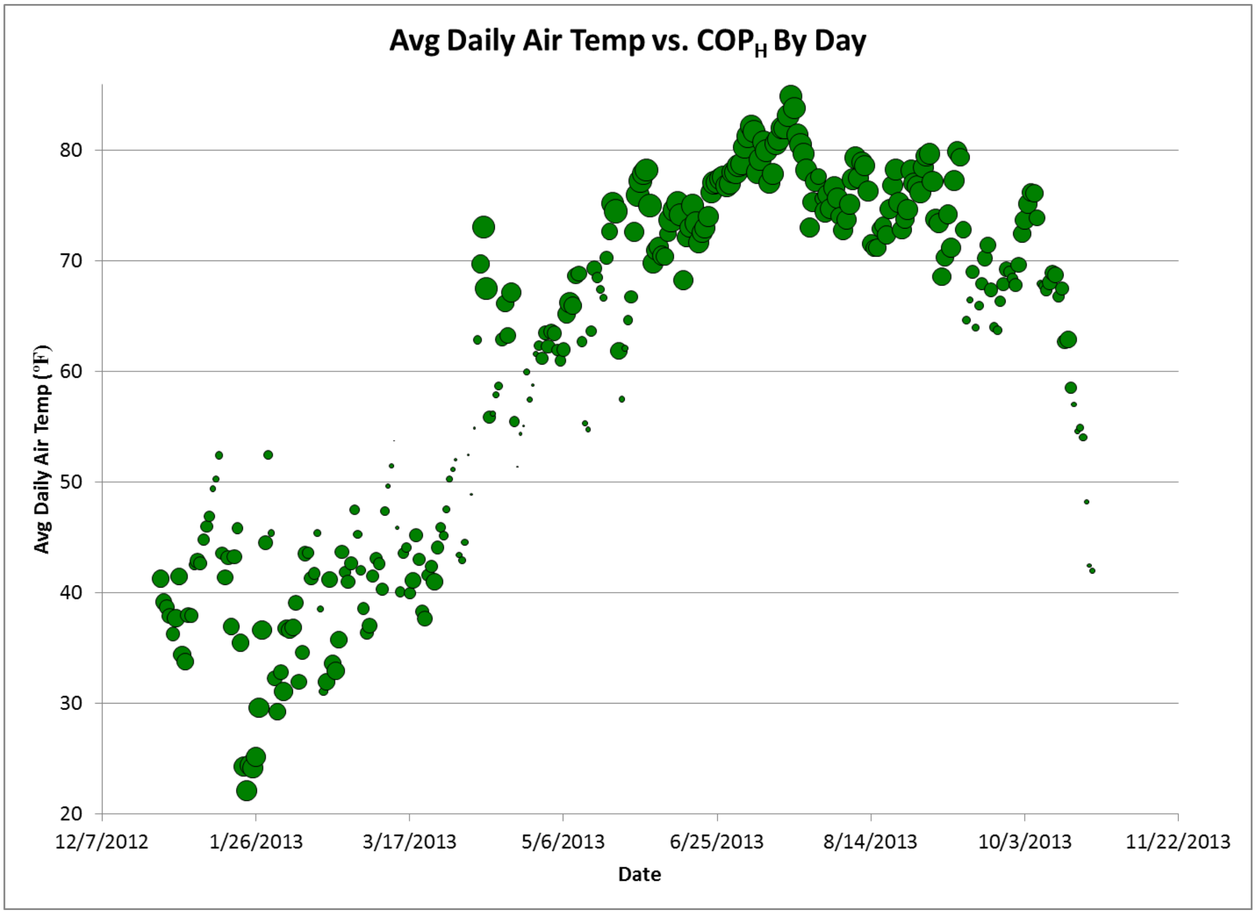


Figure 16. Average daily outdoor air temperatures (in degrees Fahrenheit) compared to geothermal system efficiency (COP_H).

For this chart, the size of the marker corresponds to the level of efficiency of the geothermal system for a given day. A larger marker signifies a higher COP$_H$ value. The system appears to be the least efficient on days where the average air temperature is about 50 to 55 degrees Fahrenheit. Figure 17 illustrates this concept further, comparing COP$_H$ values to outdoor air temperature, regardless of date:

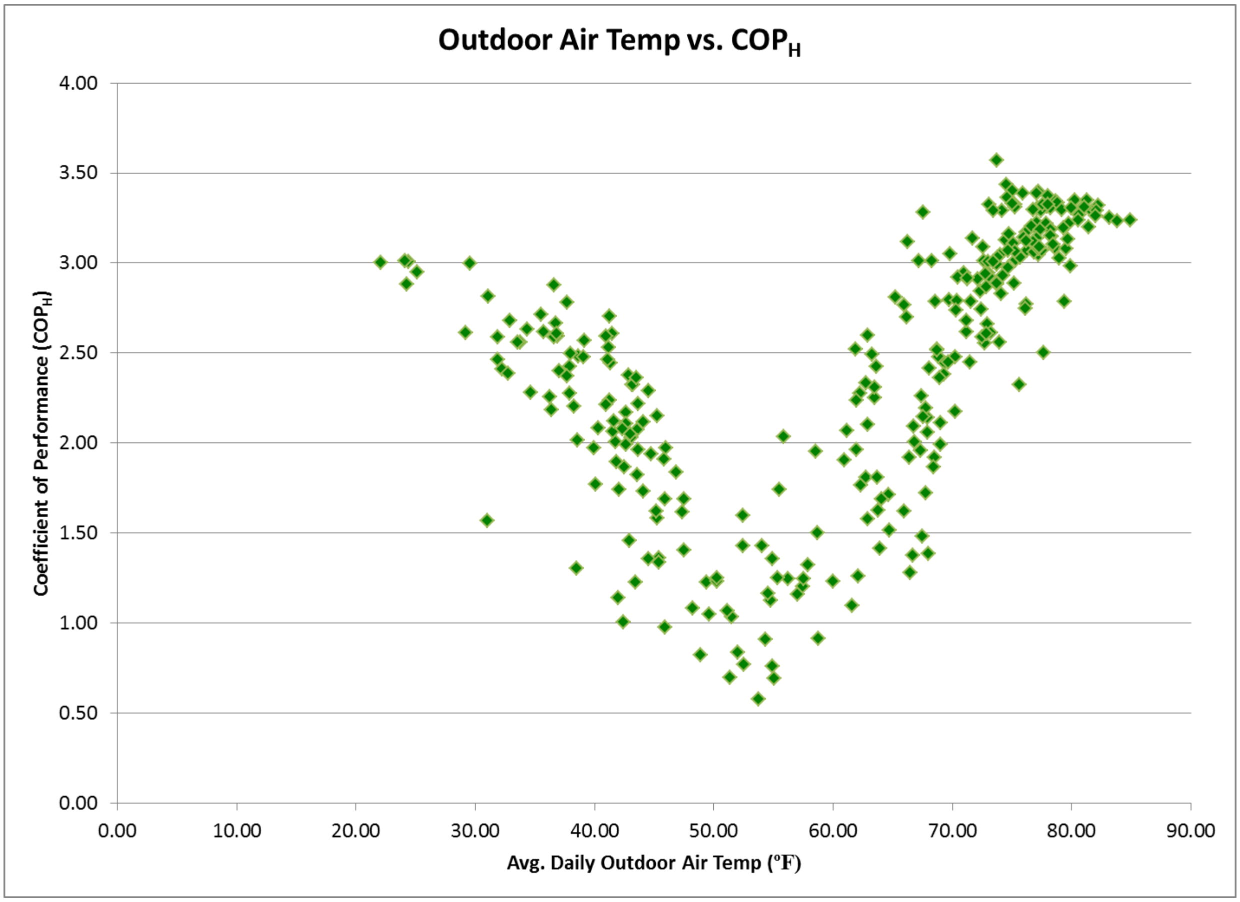


Figure 17. Geothermal system efficiency (COP$_H$) compared directly to average daily outdoor air temperature (in degrees Fahrenheit).

Again, it is apparent that the system values for efficiency appear lowest at approximately 50 to 55 degrees Fahrenheit. The reason this concept is important is because it indicates that the total values for system geothermal system efficiency (COP$_H$ values of 2.29 for heating and 2.94 for cooling) are broad generalizations and do not reflect the everyday variances in system performance. Moreover, because only the main pump house is monitored for heating power supply, the intricacies of the rest of the system are not seen. For example, heat energy can be redirected from building to building based on need, such as moving extra heat generated by students in their dormitories overnight into the lecture halls before morning classes begin. This transfer of energy would never be monitored by the main pump house as it is not transferring any heat between the ground (via the well fields) and the rest of the campus system. For this reason, there is approximately an additional 20% increase in system efficiency that is not being calculated for lack of proper monitoring stations (M. Helmke, personal communication, April 2014).

Summary and Concluding Remarks

The vertical closed-loop geothermal well system at West Chester University is a work in progress, but it is already proving to greatly increase system performance and reduce harmful gaseous emissions. Switching from the campus coal plant to the geothermal system for heating has reduced carbon dioxide by 37.43%, sulfur dioxide by 70.35%, and nitrous oxide by 72.66%. By using the geothermal system for cooling instead of older commercial air conditioning units, system efficiency has increased 47 percent. Once the system is fully completed and operational, the campus heating needs will no longer be dependent on the archaic coal plant but instead on the cleaner, more sustainable geothermal system. The results of this study make it clear that the Geothermal Initiative at West Chester University is both a profitable and rewarding method for heating and cooling at a large-scale site.

REFERENCES

1. Helmke, M. (2013, October 30). Performance of a Large Geoexchange System in Fractured Gneiss of Southeast Pennsylvania. *GSA Conference*. Lecture conducted from Geological Society of America.
2. Helmke, M. (Fall 2013). Ground-Source Heat Pumps: Everybody's Geothermal. *PCPG Newsletter*, *3*.
3. Geothermal Heat Pumps. (2012, June 24). *Energy.gov*. Retrieved April 20, 2014, from http://energy.gov/energysaver/articles/geothermal-heat-pumps
4. Power Profiler. (2014, February 26). *How clean is the electricity I use?* -. Retrieved March 27, 2014, from http://oaspub.epa.gov/powpro/ept_pack.charts
5. Energy Usage at WCU. (2014). *West Chester University*. Retrieved April 20, 2014, from https://www.wcupa.edu/sustainability/wcuenergy.asp
6. Bony, P. (Director) (2012, February 28). Geothermal Heat Pumps A - Z. *2012 Illinois Geothermal Conference*. Lecture conducted from Peoria, IL.
7. How much carbon dioxide is produced per kilowatt hour when generating electricity with fossil fuels?. (n.d.). *U.S. Energy Information Administration Independent Statistics & Analysis*. Retrieved April 20, 2014, from http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11