ADOPTING GEOTHERMAL HEAT PUMPS

ABSTRACT

Global climate change is a major problem we are facing. Thirty percent of the global greenhouse gas emissions are being produced by electricity production, while six percent is produced by buildings. Climate change is happening now. This capstone examines the way in which the use of the earth's natural properties can help combat climate change through the use of Geothermal heat pumps in the residential sector.

Camarena, Paul

SBE498

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Introduction

Global warming is a serious problem facing the world. Since the late 19th century, "average surface temperatures have increased by about 1.62 degrees Fahrenheit (0.9 degrees Celsius)" (*Climate Science Special Report: Fourth National Climate Assessment, Volume I* | 2017). Likewise, the concentration of carbon dioxide in Earth's atmosphere has increased substantially "throughout these cycles, atmospheric carbon dioxide was never higher than 300 ppm; in 2017, it reached 405.0 ppm" (*Climate Change: Atmospheric Carbon Dioxide* | *NOAA Climate.Gov*).

The Southwestern United States is experiencing drought and dramatic temperature increases. From 2001 to 2010 there have been drastic changes to the temperature "the warmest in the 110-year instrumental record, with temperatures almost 2°F higher than historic averages"(Garfin et al., (2014). Having higher temperatures can cause many health problems for the residents of the Southwest. For instance, a severe heat wave in California in 2006 resulted in high mortality, especially among elderly populations"(Garfin et al., 2014). This heat wave caused there to be an increase in the use of electricity causing an electrical blackout that caused many residents to stay without power and have no access to air conditioning.

Climate change will drive electric use higher, possibly requiring power plants, some of which are powered by CO2 emitting fossil fuels, to increase their output. Climate change could lead to increased burning of fossil fuels and more CO2 in the atmosphere. Coal-burning power plants are "responsible for 42 percent of US mercury emissions, a toxic heavy metal that can damage the nervous, digestive, and immune systems (*Coal and Air Pollution* | *Union of Concerned Scientists*). Power plant that burns coal make nearby areas at risk for potential health hazards. There are several alternatives to the use of coal. The most popular is natural gas, although it may not be the best.

While there is an abundant amount of natural gas, it still releases pollutants to the atmosphere. The optimal alternative is the use of renewable energy such as solar, wind and geothermal.

In order to adapt to future conditions caused by climate change, such as electrical blackouts, we need to develop and implement new technology to keep our homes and buildings cool. Geothermal heat pumps may be the answer to reducing the temperature inside a home. Heat pumps take advantage of the temperature difference between the ambient ground temperature and that of the air to heat or cool a home. Heat pumps are similar to refrigerators as "heat pumps operate on the basic principle that fluid absorbs heat when it evaporates into a gas, and likewise gives off heat when it condenses back into a liquid"(*Geothermal Heat Pumps | WBDG Whole Building Design Guide*). A geothermal heat pump system comprises three parts: the heat exchanger, the pump unit, and the air delivery system. The heat exchanger is buried in the ground, where year-round temperatures range from 50 degrees to 75 degrees. In winter, the heat exchanger removes all of its heat and transfers it to the building while in the summer it does the opposite. It draws out all of the heat from the house and transfers it to the ground. According to the National Renewable Energy laboratory, geothermal heat pumps "use much less energy than conventional heating systems, since they draw heat directly from the ground. Also, geothermal pumps are more efficient when cooling a home. Not only does this save energy and money, but it also reduces air pollution".(*Geothermal Heat Pump Basics | NREL*) This makes the combination of solar panels and geothermal a winning team when combating climate change.

In Tucson, the Tucson Electric Power company has changed the way it produces power for the city. In 1982 the U.S. Department of Energy ordered TEP to convert its natural gas power plants to coal burning plants. Then in 2015, TEP switched to natural gas and other sustainable resources stating, "TEP is increasing its use of natural gas and relying more heavily on its expanding renewable energy portfolio, which now includes more than 400 megawatts of solar, wind and other resources — enough to meet the annual electric needs of more than 84,000 homes" (*TEP to End Use of Coal, Switch Primarily to Natural Gas at Tucson Power Plant – Tucson Electric Power*). Using more renewable and clean energy sources will make our city a better place for everyone.

This capstone will focus on the impacts of geothermal heat pumps in residential applications in the city of Tucson Arizona. The goal is to understand why geothermal heat pumps are not a primary or secondary source of cooling and heating of homes. By understanding the reason why homeowners are not using this resource, we can help create a need for geothermal heat pumps. This study is focused on homes in order to provide homeowners with more information on this technology while empowering them to make positive decisions for their heating and cooling.

Methods

The study location is Tucson, Arizona because it is a large enough city to provide good data and it is small enough to collect a sample size quickly. Another characteristic of Tucson is that there is an estimated population or 520,000 according to the 2010 census. These reasons, plus the consistent temperatures, are what make Tucson a great place to research geothermal heat pumps.

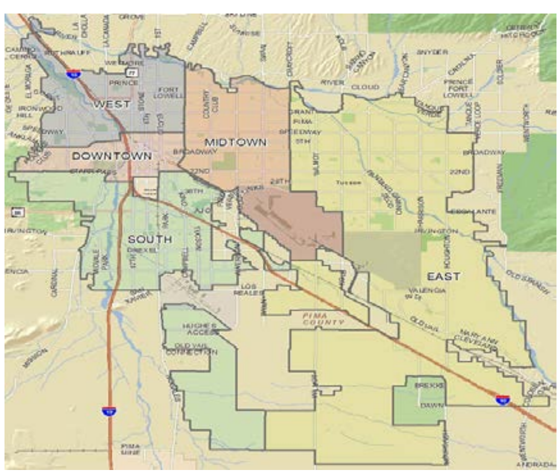


Figure 1. MAP OF STUDY LOCATION

This project uses an online survey and will conduct an energy audit on a basic one-story home. Both research methods complement each other. The first step in conducting the research is to run an energy audit on a single-story home and figure out how much electricity is being used by an HVAC system. This home will then be used to generate a model to see how much of a difference in energy usage could be achieved by implementing a geothermal heat pump. The next step is to create and conduct an online questionnaire. This questionnaire will ask respondents, homeowners in Tucson, if they understand what a geothermal heat pump is. Next, there will be a short animation showing the findings from the energy audit. After the animation, there will be two final questions asking the user if they are interested in switching over to a geothermal heat pump and what barriers are preventing them from doing so.

The homeowners reached are those that have already implemented Photovoltaic technology to their homes. The number of homeowners reached was roughly 50-100 homeowners, and the questionnaire was distributed via e-mail — the reason why is because homeowners can change their homes to suit their needs better. Even though the homeowners have already implemented solar energy, this study hypothesizes that when shown the benefits of Geothermal energy they will want to learn more about this technology.

Literature review

The history of Geothermal energy

Geothermal energy is not a new energy source. Its use in, "North America occurred more than 10,000 years ago with the settlement of Paleo-Indians at hot springs. The springs served as a source of warmth and cleansing, their minerals as a source of healing"(*A History of Geothermal Energy in America | Department of Energy*)). Since there is no cost to using geothermal energy, beyond any infrastructure to access it, it has been used since its discovery as a source for warmth. In 1830, in the city of Hot Springs, Arkansas the uses of geothermal energy were first commercialized by " the use of three spring-fed baths in a wooden tub, and the first known commercial use of geothermal energy occurred (*A History of Geothermal Energy in America | Department of Energy*)). Throughout the history of the world there have been many uses for geothermal for instance in 1930 the "first commercial greenhouse use of geothermal energy" and in that same year "Charles Lieb developed the first downhole heat exchanger and used it to heat his home(*The History of Geothermal Energy in America*). Then a couple of years later in 1948, a Professor of Ohio State developed the first ground source heat pump to be used at his home. (*The History of Geothermal Energy in America*).

History of Geothermal Heat Pumps

The first patent for a ground source heat pump was in 1912, "applied for by Heinrich Zoelly, of some fame in water and steam turbine design and with the development of steam turbine locomotives." (Sanner, 2017). Then in 1938, the Swiss used a ground source heat pump to heat a town hall. This heat pump worked by using the river water as a heat source- this was advantages because of the restriction on coal during World War II (Sanner, 2017). This heat pump supplied rough 100kw of heat and had a "very long service life of 63 years, with the compressor replaced in 1964, before being retired in 2001"(Sanner, 2017). While in North America the mid-1940s was when geothermal heat pump gained traction. In Indianapolis, in 1945, the first ground source heat pump was installed. This heat pump was monitored "from October 1945 to May 1946 and used 6357 kWh of electricity during 1630 operating hours in this winter with lows of -24 °C. The heat pump saved 5.1 tons of coal or 2970 l of fuel oil which would be required according to calculations for conventional heating" (Sanner, 2017). Geothermal heat pumps have only continued to improve.

Home Heating and Cooling

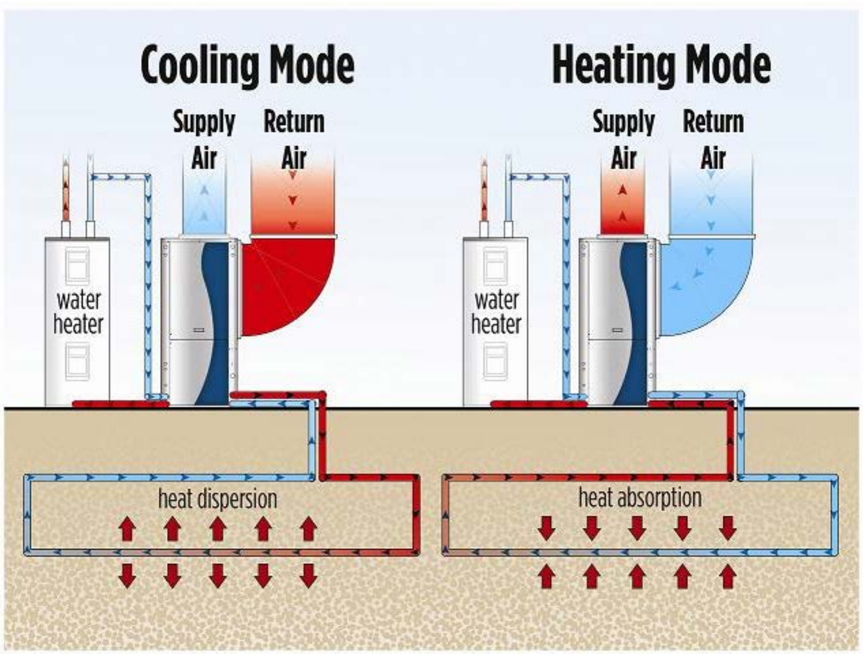
It is important to understand the fundamentals of heating and cooling a house. There are many methods of heating and cooling such as Evaporative Coolers, Ductless Mini-Split Air Conditioners, Furnaces, Electric Space Heaters and many more. Each of these systems functions in different ways, for instance, the way that evaporative coolers work is "by pulling fresh outside air through moist pads where the air is cooled by evaporation. The cooler air is then circulated through a house. An evaporative cooler can lower the temperature of outside air by as much as 30 degrees." (*Types of Cooling Systems | Smarter House*). The way that Ductless Mini-Split Air Conditioners work is that they "use an outside compressor/condenser and indoor air handling units. The difference is that each room or zone to be cooled has its air handler. Each indoor unit is connected to the outdoor unit via a conduit carrying the power and refrigerant lines" (*Types of Cooling Systems | Smarter House*). The way that a furnace works is that "fuel is mixed with air and burned. The flames heat a metal heat exchanger where the heat is transferred to the air. Air is pushed through the heat exchanger by the "air handler's" furnace fan and then forced through the ductwork downstream of the heat exchanger." (*Types of Cooling Systems | Smarter House*). The way that Electric Space Heaters work is that "they convert electric current from the wall socket directly into heat, like a toaster or clothes iron." Each of these systems works independently.

The Geothermal heat pumps may offer the best solution to heating and cooling. The heating and cooling industry "has long been dealing with the heating and cooling of buildings as separate entities with separate groups of designers, specifiers and installers for each discipline" (Hundy, Trott, Welch, et al., 2016). However, a geothermal heat pump is the combination of an air conditioner and a heater. There are a couple of drawbacks to these systems such: the higher cost of installation and uses electricity. (*Disadvantages Ground Source Heat Pumps | Advantages Ground Source Heat Pumps |*

Problems with GSHPs | Pros Cons Gshp | Geothermal Heat Pumps), however, the positives of this system is that these systems can heat a house at a "lower cost than direct fossil fuel heating" (Hundy, Trott, Welch, et al., 2016).

How Geothermal Works

Geothermal heat pumps rely on the ground to exchange heat because at a certain depth "temperatures remain relatively stable and there are a number ways in which to extract heat from the



ground" (Hundy, Trott, Welch, et al., 2016). There are also different types of GSHP there is: Horizontal, vertical, pound and open loop system each of these types has their benefit. According to energy saver, the Pound is the lowest cost option since there is not digging cost "A supply line pipe is run underground from the building to the water and coiled into circles at least eight feet under the surface to prevent freezing. The coils should only be placed in a water source that meets minimum volume, depth, and quality criteria."(*Geothermal Heat Pumps | Department of Energy*)

Figure 2.GEOTHERMAL HEAT PUMP

Explanation of each of the types of Geothermal heat pumps

According to Energy.gov, there are four main types of looped systems, and each of them is distinct from one another. Three of these looped systems are closed looped while the fourth one is an open looped system. The closed looped systems are horizon, vertical and pound/ lake systems. An open looped systems work by using groundwater to run through the system, it exchanges the heat, and then finally it is returned to the ground. "Two wells are drilled to reach the water source and install the pipes. Also known as a direct exchange, the open loop system will pump the water directly to the heat pump, where the heat is extracted. Then the water is released back into the ground through a second well, called the rejection well"(*Types of Ground Source Heat Pumps (2018) | GreenMatch*).

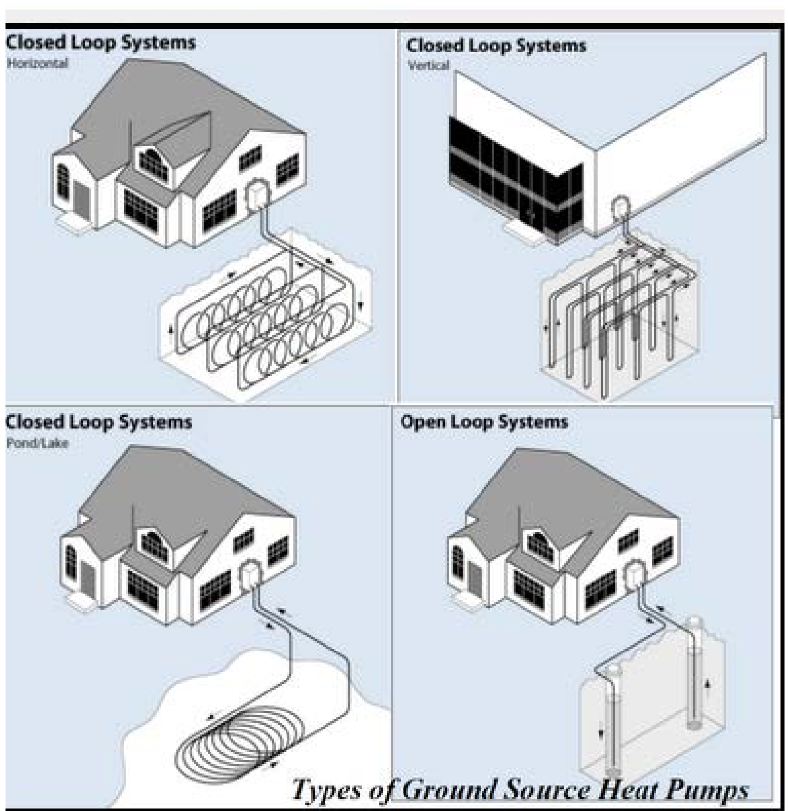


Figure 3. TYPES OF GEOTHERMAL HEAT PUMPS

The way a closed loop system work is a little different. Closed loop systems require a system of pipes to be buried underground that circulates antifreeze. "A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze solution in the closed loop."(*Geothermal Heat Pumps | Department of Energy*). The variation of the closed loop systems all depends on what these systems are going to be used for and how much space is available. The Horizontal system is mainly used in a new residential home when space is plentiful also this method is the most cost-effective "looping pipe allows more pipe in a shorter trench, which cuts down on installation costs and makes horizontal installation possible in areas it would not be with conventional horizontal applications." (*Geothermal Heat Pumps | Department of Energy*). While the vertical system is mostly used for large commercial buildings where land is limited. The benefit of having a vertical system is that it will not disturb the landscape. The vertical system requires holes to be drilled 100 to 400 feet deep every 20 feet apart. The last system is Pound/ Lake system which requires, "A supply line pipe is run underground from the building to the water and coiled into circles at least eight feet under the surface" (*Geothermal Heat Pumps | Department of Energy*). The cost of geothermal heat pumps is high about double than a regular system. For a home "of 2500 square feet, with a heating load of 60,000 BTU and a cooling load of 60,000 BTU will cost between $20,000 to $25,000 to install" (*Geothermal Heat Pumps | Department of Energy*). Even though there is a high cost associated with a geothermal heat pump the payback for this system ranges from 2-10 year and the life span of this system is 18-23 years- almost double the lifespan of conventional HVAC systems. Another benefit of having a geothermal heat pump is that it can reduce utility bill by 40% to 60%. (*Geothermal Heat Pumps | Department of Energy*).

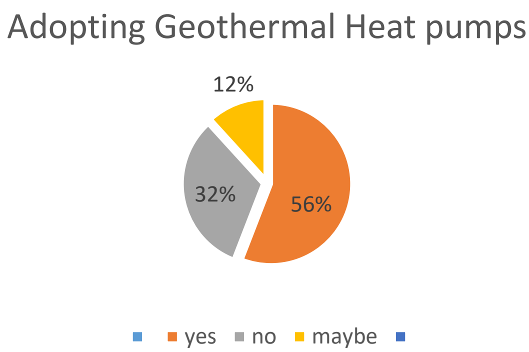
The efficiency of these heat pumps is remarkable. "According to the Environmental Protection Agency, Geothermal ground source heat pump systems are one of the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available."(*Geothermal Heat*

Pumps: Environmental Benefits and Efficiency). On average these systems are "48 percent more efficient than gas furnaces, 75 percent more efficient than oil furnaces, and 43 percent more efficient when in the cooling mode"(*Geothermal Heat Pump Basics | NREL*). These systems do not burn any fossil fuel to produce heat, so this eliminates any emission that can leak inside of a home. Geothermal heat pumps on 3-ton residents produce one pound less carbon per hour capered to conventional systems, this means, "installation of 100,000 units of residential geothermal systems can reduce greenhouse gas emissions by almost 1.1 million metric tons of carbon equivalents. That would be the equivalent of removing 58,700 cars from our highways or planting more than 120,000 acres of trees."(*Geothermal Heat Pumps | Department of Energy*).

Data/Results/Discussion

The data collected from the survey was interesting even with small sample size. The survey used Qualtrics to collect the results. There was a total of 40 people that participated in the 7-question survey. This survey is broken down into three parts the first part of this survey is asking general questions. Such as "how do you heat and cool your home" and "Do you feel that you are paying too much for heating and cooling? Explain?". The second part of this survey is learning the benefits of a geothermal system and asking the surveyor if this technology is interesting. This section listed the benefits of the geothermal heat pump and then asked: "Are you willing to switch over to geothermal energy?" Then finally the last part is where put the results from the energy10 file, and also included a section where the surveyors can ask questions.

The results show that the majority of surveyors say that they pay way too much for electricity and 75 percent of those surveyed heat and cool their homes by air conditioning and electric heaters. After asking if people knew anything about geothermal heat pumps, they were asked if they were will to switch over to the geothermal heat pump.



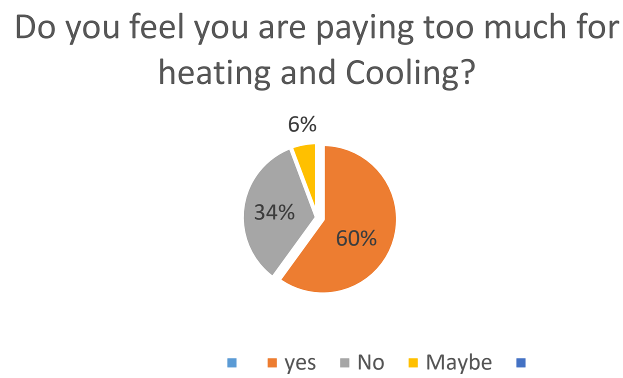


Figure 4 QUESTIONS

45 percent said they are willing to switch over while 52.5 percent were not too sure. After showing the results of the energy10 file, they were asked if they were willing to adopt geothermal energy to their home. The results were that roughly 52.5 of the participants were willing to adopt this technology. The final question showed that there was much interest in this type of technology.

The questions left in the open section of the survey included, "I am currently renting, but when looking for my next home will look into the heating and cooling systems using geothermal energy." "I will also tell friends who currently own homes." "What is the cost of a geothermal unit?" "How many people have geothermal units?" "What's the annual cost of for geothermal unit?" "How can it work with solar/wind energy systems?" and "How does solar energy and geothermal energy work together? If they do at all".

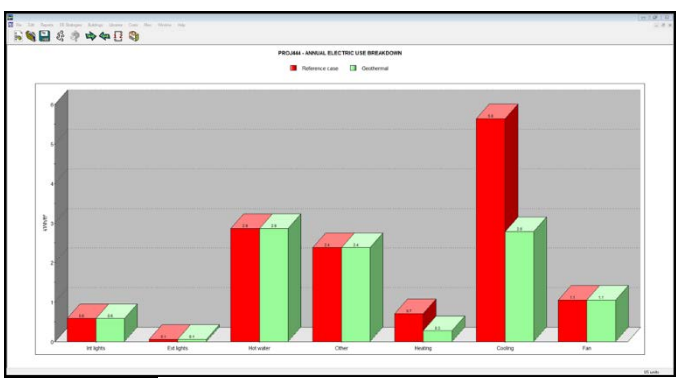
The data from my energy analysis was more numerical. When conducting the energy10 analysis, it started with two homes. The first home was the reference case and the second was labeled as Geothermal. Both of these homes were identical; they both were 2184 square feet. They both used

Description:	Reference case	Geothermal
Scheme Number:	7 / Saved	6 / Not Saved
Library Name:	ARCHIVELIB	ARCHIVELIB
Simulation status, Thermal/DL	valid/NA	valid/NA
Weather file:	TUCSON.ET1	TUCSON.ET1
Floor Area, ft^2	2184.0	2184.0
Surface Area, ft^2	6085.1	6085.1
Volume, ft^3	19656.0	19656.0
Total Conduction UA, Btu/h-F	303.7	303.7
Average U-value, Btu/hr-ft^2-F	0.050	0.050
Wall Construction	steelstud 6 poly, R=19.2	steelstud 6 poly, R=19.2
Roof Construction	flat r-38, R=38.0,etc	flat r-38, R=38.0,etc
Floor type, insulation	Slab on Grade, Reff=57.2	Slab on Grade, Reff=57.2
Window Construction	4060 low-e al/b, U=0.31	4060 low-e al/b, U=0.31
Window Shading	40 deg latitude	40 deg latitude
Wall total gross area, ft^2	1717	1717
Roof total gross area, ft^2	2184	2184
Ground total gross area, ft^2	2184	2184
Window total gross area, ft^2	432	432
Windows (N/E/S/W:Roof)	3/2/10/1:2	3/2/10/1:2
Glazing name	double low-e, U=0.26	double low-e, U=0.26
Operating parameters for zone 1		
HVAC system	Air Source Heat Pump/ER Backup	Air Source Heat Pump/ER Backup
Rated Output (Heat/SCool/TCool),kBtu/h	26/42/56	26/42/56
Rated Air Flow/MOOA,cfm	1955/0	1955/0
Heating thermostat	72.0 °F, setback to 67.0 °F	72.0 °F, setback to 67.0 °F
Cooling thermostat	73.0 °F, setup to 78.0 °F	73.0 °F, setup to 78.0 °F
Heat/cool performance	COP=0.0,EER=8.9	COP=0.0,EER=18.0
Economizer?/type	no/NA	no/NA
Duct leaks/conduction losses, total %	11/10	11/10
Peak Gains; IL,EL,HW,OT; W/ft^2	0.15/0.03/0.66/0.36	0.15/0.03/0.66/0.36
Added mass?	1092 ft^2, 8in cmu	1092 ft^2, 8in cmu
Daylighting?	yes, continuous dimming	yes, continuous dimming
Infiltration, in^2	ELA=61.8	ELA=61.8
Results:		
Energy cost	0.400$/Therm,0.012$/kWh,2.470$/kW	0.400$/Therm,0.012$/kWh,2.470$/kW
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec
Energy use, kBtu	99149	74685
Energy cost, $	555	398
Saved by daylighting, kWh	-	NA
Total Electric (**), kWh	29056	21887
(** less Sellback, if any)		
Internal/External lights, kWh	1287/140	1287/140
Heating/Cooling/Fan, kWh	1548/12319/2298	607/6091/2298
Heat Pump/Elec. Res., kWh	1454/94	514/94
Hot water/Other, kWh	6261/5202	6261/5202
Peak Electric, kW	8.1	5.3
Fuel, hw/heat/total, kBtu	0/0/0	0/0/0
Emissions, CO2/SO2/NOx, lbs	39052/230/119	29416/173/90
Construction Costs	406594	411187
Life-Cycle Cost	427165	426763

Figure 5. ENERGY 10 ANALYSIS

Double Low-E windows, they are the same home, but the difference is the Mechanical systems. The system that is used in the case is an Air source heat pump while the system that is used in the geothermal house is a geothermal heat pump. The rated airflow for both of these systems is the same; it is 1955. All of the variables such as the setbacks for heating and cool, infiltration, Duct leaks, rated output and peak gains are all of the same for both of these systems they only thing that has changed is the performance of the system. The energy efficiency ratio or the EER for the references case was 8.9 while the EER for the geothermal system was 18; these efficiency were estimated. The change in efficiency is want to be changed causing there to be an increase in savings.

The results of the Energy10 file showed that there is a major saving when using a geothermal heat pump. Comparing the construction cost of the reference case $406,594 and the geothermal home $411,187 there is a difference of roughly five thousand dollars. The increase in cost for the geothermal home is caused because of the extra cost associated with the geothermal heat pump. However, the life-cycle cost of the reference case is $427,165 while the life cycle cost of the geothermal home is $426,763 resulting in a saving of 402 dollars over the lifetime of the home. The energy usage in one year for the reference case is 99,149 kBtu and for the geothermal case is 76,685 kBtu. The amount of energy used for heating for the reference case (Air-to-Air heat pump) was 2.4(kBtu/ft^2), and that dropped to 1.0 for the geothermal heat pump 1.4(kBtu/ft^2), and the same can be said for cooling the reference case was at 18.2 and that dropped down to 9.5 for the heat pump. Throughout the energy simulation, it was clear that geothermal heat pump outperformed the reference case. The model was able to measure different variables such as annual energy cost, monthly electric demand peaks, and the annual electric use breakdown in order to prove that the geothermal heat pump was far superior.



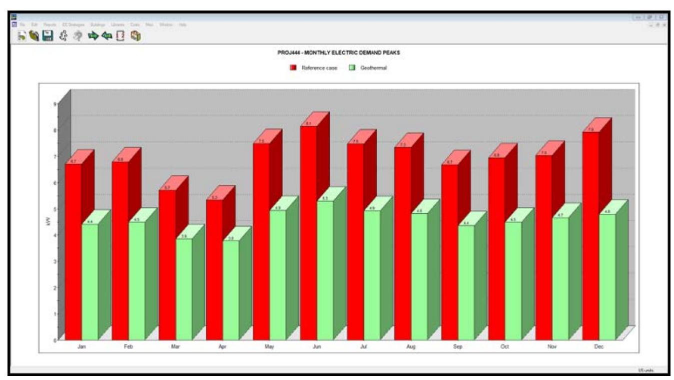


Figure 6. ENERGY10 FILE AIR TO AIR HEAT PUMP VS GEOTHERMAL HEAT PUMP

The results from the Energy 10 file are very important because the show that geothermal heat pump technology will outperform. Even though the geothermal heat pump outperformed, the study made sure that this simulation used the Tucson weather file. This is important because the geothermal system is commonly used in colder climates and work better in these types of climates. However, it is important to note that during the whole year the geothermal heat pump used less electricity. When comparing the electrical usage, the geothermal heat pump uses half the electricity that the air to air heat pump uses for heating and cooling. This is important because the geothermal heat pump system will be able to save the homeowners money since it does not use as much electrical power.

Conclusion

Global warming is a serious problem that is occurring, and this will drive the use of electricity to increase substantially. With more and more people using their air conditioning more often it is important that we change that we heat and cool our homes. The answer to this problem is the technology that has been around since the 1900's: Geothermal Heat Pumps, this system is an all in one system that can heat and cool a home without the need of others systems. By adding this system homeowners can see a reduction in their electricity bill, their bill is reduced by 40% to 60%. (*Geothermal Heat Pumps | Department of Energy*). The key finding in the survey was that many of the people who took the survey were interested in learning more about the benefits of geothermal energy. Another key finding in the survey was that there was a lack of knowledge of geothermal heat pumps. The key finding from the Energy10 file showed the Department of Energy was correct and that by installing a geothermal heat pump there is a reduction in electricity. The limits for the survey was the sample size- a larger size would have given clearer results for the City of Tucson. A recommendation would be to compare not only the efficiency but the overall cost of the system. Since there are many manufacturers of these systems, future research should take one manufacturer and compare their geothermal and the air system and show the difference in price. Studies should also use the efficiency of the two systems that are made by the same manufacturer. Global warming is a serious problem that the world is facing. By implementing a geothermal heat pump, this is one of the solutions to combating global warming.

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