Community Geothermal

ME 589 Final Report

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Team 881-4

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Abstract

Selecting a design for a home involves choosing a heating and cooling system. These initial decisions have a major impact on the on-going heating and cooling costs. When designing a subdivision or community of homes, is it possible to make initial decisions for the whole community and reduce the capital cost of equipment and labor? Could this encourage builders and buyers to make more energy efficient choices? Several types of home heating and cooling technologies will be considered, with an emphasis on the implementation of a community geothermal system in new housing developments.

1 Executive Summary

In the United States, households consume approximately twenty percent of the energy consumed annually. Of this twenty percent, about half is used for heating and cooling the home. Most of the homes in the U.S. use forced air heating with electric air conditioning. These systems are not energy efficient and rely on fossil fuels to operate, primarily natural gas. With natural gas reserves growing every year in the U.S., prices dropping and constant demand, it is likely natural gas will be the prevailing energy source for home heating for the near term future, and greenhouse gases will continue to rise. That is unless there is a way to utilize the heat of the Earth, creating a sustainable resource for the foreseeable future of mankind.

Geothermal heating and cooling is a technology that utilizes the natural heating of the Earth. By implementing this in a community layout, it is a cost competitive option to the baseline system that also allows for the emissions to be halved. The team began by researching alternatives to conventional heating and cooling systems. Few existing technologies provided reasonable alternatives. A needs assessment was conducted in which homeowners, builders, and city planners were interviewed. This allowed a persona to be developed that we will market our product to. This persona is a member of a municipality that is knowledgeable in city planning and development, acquiring funds for public service projects, and has a continuing need for revenues to support daily operations. Specifications were created from the customer requirements and a number of potential concepts were developed that could meet this need. Concept selection matrices were used to compare the technologies, construction and implementation methods, and payment options to determine the optimal solution. The alpha design is to implement a community geothermal system as a regulated utility that is operated by the city. In order to validate this concept as well as the plan to implement it, builders and city planners were contacted for feedback.

The final design is much different than both a conventional forced air system and a conventional geothermal system. It contains a central pumping station, which utilizes geothermal wells and a heat pump to generate a constant temperature hot and cold water loop which is distributed throughout the neighborhood. Each home contains a simple air handling unit that takes in either the hot or cold water and exchanges heat with the air to condition the home. This system is also used to heat hot water, thus it completely eliminates the need for fossil fuels, which reduces fluctuations in energy bills and reduces greenhouse gas production.

In order to take the concept to reality, a business plan was developed which calls for our company to be a design and construction firm that installs community geothermal systems with a focus on new housing developments. The product would be marketed to municipalities in order to gain their interest and the firm would help them apply for government funding to pay for the upfront cost of the system. Once installed, the system would be operated by the city and used to generate a sustainable revenue stream for the city that would offer competitive cost heating and cooling to its customers in the neighborhood. Since geothermal technology already exists and has been implemented in a similar way in a commercial setting, the technological risk is rather low for the customers. In order for the business to thrive, government funding would be relied upon for the initial projects and eventually, when this funding is no longer available, would rely on the testimonials of customers to install additional systems across the nation. Geothermal systems can provide cost effective, environmentally sustainable solutions today. It is our goal to see these systems expand.

2 Introduction

This report contains an extensive explanation of the processes that were followed in order to develop our concept and our plan to turn it into a reality. It contains a literature review of alternatives to conventional heating and cooling technology, a summary of our ethnographic research and the interviews that we conducted in order to develop our persona, a description of our customer requirements and specifications, a sustainability analysis of community geothermal systems as well as baseline systems, concept generation and selection, alpha design description, alpha design feedback and final design, a detailed business and marketing plan, and reflections on the outcome of our project. We believe that the idea of community geothermal systems is not farfetched and is something that could revolutionize the home heating and cooling industry for the better.

3 Product Functional Status

The global economy has grown over the years to be dependent on cheap and readily available fossil fuels; however, as global energy consumption continues to grow this trend of fossil fuel consumption is not sustainable. Households in the United States comprise about twenty percent of the primary energy consumed nationally. Of this energy, heating and cooling comprise a large portion of the energy consumed in the household at about 36% for space heating followed by water heating at 15%, refrigerators at 12% and space cooling at 10% (NES 1992). From this data, it is clear that home heating and cooling is an area that can be investigated for improvement. There are a number of different options available to suit the heating and cooling needs of new homeowners. The most common and widely used arrangement is forced air with a fuel burning furnace and electric air conditioning unit. This setup will serve as the baseline technology for our research and the basis for what other technologies will be compared to. Besides conventional forced air, we decided to evaluate some of the other technologies that reduce the use of electricity or the use of fuel.

3.1 Heating/Cooling Technologies

This section will give an overview of a range of available heating and cooling options and how they compare to conventional forced air technology. Since our focus is on new construction in Michigan, all of the systems will need to be able to provide sufficient heat in the winter and sufficient cooling in the summer to keep the home at a comfortable temperature year round.

3.1.1 Conventional Forced Air

The majority of homes in the United States use forced air technology to heat and cool their home (US DOE 2012). The system consists of duct work routed throughout the home to distribute the conditioned air and return duct work to return air to the furnace to be conditioned. The furnace contains an electrically powered fan that forces the air throughout the home as seen in Figure 1 - a. In the winter, the furnace will burn either natural gas, propane, or oil depending on the availability of fuel in the area (US DOE 2012). Typical air conditioning systems utilize the fan inside the furnace to distribute the air as seen in Figure 1 - b. They circulate a refrigerant between an evaporator and a condenser. The evaporator removes heat from the indoors while the condenser releases this heat to the outdoors. Furnaces can have annual fuel utilization efficiencies (AFUE) as high as 98.5%, which means that 98.5% of the energy in the fossil fuel is used to heat the home (US DOE 2012). A downside of conventional systems is that they rely on fossil fuels to produce heat.

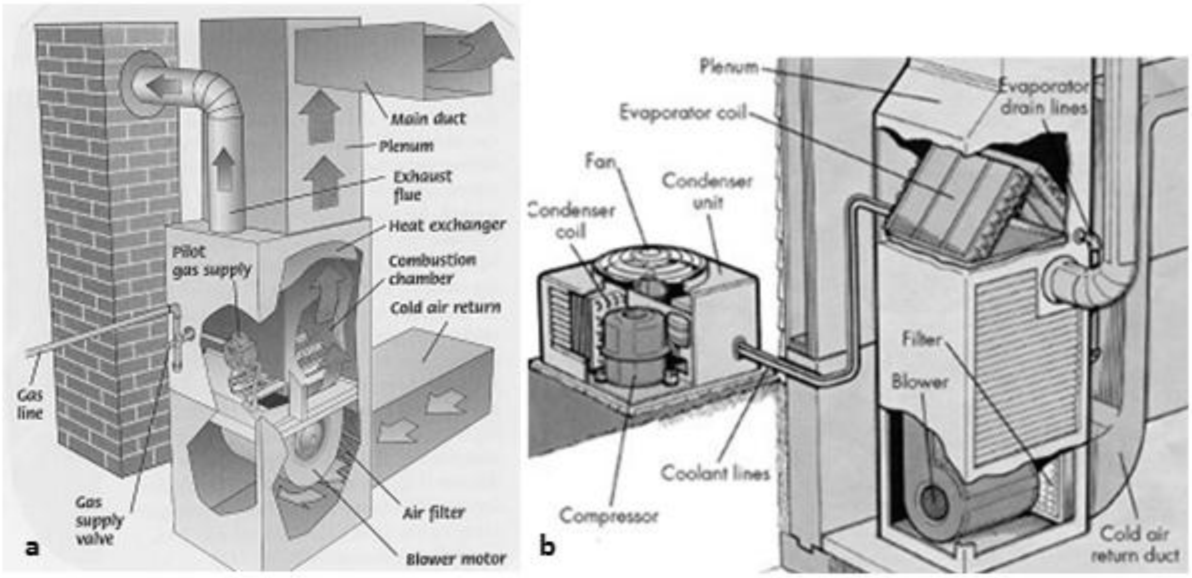


Figure 1: Conventional forced air (a) heating (The Able Group n.d.) and (b) cooling (The Prime Buyers Report 2013) systems

3.1.2 Ductless Electric

Another technology that is used is full electric heating and cooling. These systems do not require the ducting of conventional forced air systems. The most commonly used method for electric heating and cooling is a split zone system (Mitsubishi Electric 2013). These systems involve a single outdoor unit connected via refrigerant lines, control lines, and power lines to multiple air handling units located in different rooms. Figure 2 shows an example of a split zone system, but only shows one indoor unit connected. The air handling units can be controlled separately allowing for variable levels of temperature conditioning across different rooms. This type of heating and cooling is typically used to retrofit existing homes that use electric baseboard heating (which is very inefficient) and/or window air conditioning units (which, if older, are also very inefficient) (Energy Star n.d.). These systems may not be able to provide sufficient heating on very cold days, so a backup system may be required depending on the climate (Energy Star n.d.).

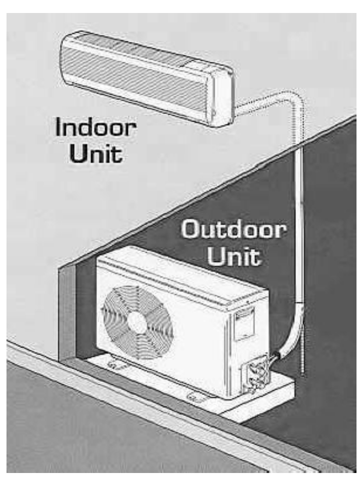


Figure 2: Layout of a ductless heating and cooling system (Gettum 2011)

3.1.3 Solar Heating w/ Conventional Cooling

There are two types of solar heating – active and passive. Passive solar heating does not involve any heating and cooling equipment, but rather it tailors the design of the house to benefit from the greenhouse effect. This means that the south facing side of the house must have an unobstructed view of the sun and it must have the right amount of windows in order to not overheat or under heat the home (US DOE 2013). Due to requiring an unobstructed view of the sun and for the south facing side of the home to be built a certain way, this technology cannot be adopted everywhere. For example, if a housing community is to be built in a wooded area, not all of the homes could have a clear view of the sun.

Active solar heating involves solar liquid collectors that capture the suns energy to heat water or other fluids as seen in Figure 3. This heated fluid is then stored in a tank and can be distributed throughout the house via radiant flooring, hot water baseboards, or forced air systems (US DOE 2012). Oftentimes, active solar systems will required a backup heating source, such as a boiler, in order to heat the fluid enough to effectively heat the home. In the summertime, a cooling system will be required to cool the home. However, active solar heating systems can be used to heat domestic hot water in the summer. Similar to passive solar heating, the home requires a consistent view of the sun all winter long in order to be effective.

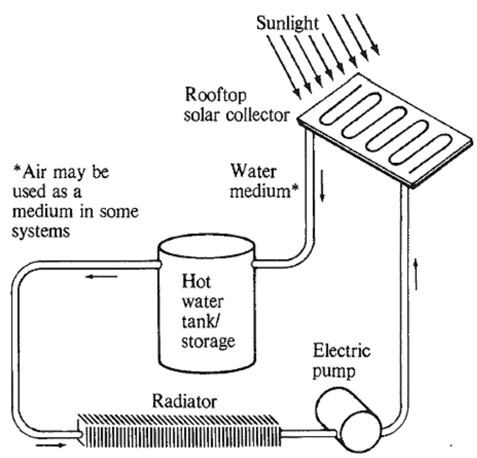


Figure 3: Diagram explaining active solar heating with radiator heat distribution (allBusiness 2004)

3.1.4 Geothermal

Geothermal systems utilize the energy of the Earth to provide both heating and cooling for the home. They are also called ground source heat pumps or GHSPs. The temperature below the Earth's surface remains constant approximately 30 feet below the surface regardless of the season (C.O. Popiel 2001). There is also less and less short term variation in soil temperature as depth increases. Geothermal systems utilize the Earth as a heat source or a heat sink (depending on the season) by taking advantage of this constant temperature source year round. There are two different types of geothermal systems – open and closed loop. Each system contains the same type of ductwork in the home as conventional forced air systems as well as a means to circulate the air throughout the home. Each system also involves pumping of a fluid through a heat pump which adds or removes the heat to/from the air through convection. Open loop systems (Figure 4 - a) utilize a well or other underground water source. This water is pumped directly through the system and returns to the well or is discharged into a pond (US DOE 2012). Open loop systems depend on a consistent water source for their operation so may not be the best option if this is not available. Closed loop systems typically use a heat transfer fluid other than water for their operation. They are called closed loop, because all of the working fluid is contained in the system and is not discharged from the system. Closed loops can either be installed horizontally underground, vertically underground, or can circulate through a lake or pond to exchange heat from the fluid (Figure 4 – b,c,d). Which system is used and loop efficiency depends on the land available, soil condition, and installation costs. Vertical loop systems are space efficient but may be more expensive to install due to the drilling of deep wells. Horizontal loop systems require more land, but do not require well drilling. Pond/lake systems are likely the lowest cost to install, but requires a body of water. While the geothermal loop may provide sufficient energy to condition the home the majority of the time, it may run short on very hot or very cold days. When this is the case, the geothermal heat pump has a built in electrical backup that will turn on and make up for the difference in performance (Geothermal Genius 2013). Either type of geothermal systems can also be used to preheat hot water for the home, thus reducing the energy required to produce domestic hot water (US DOE 2012).

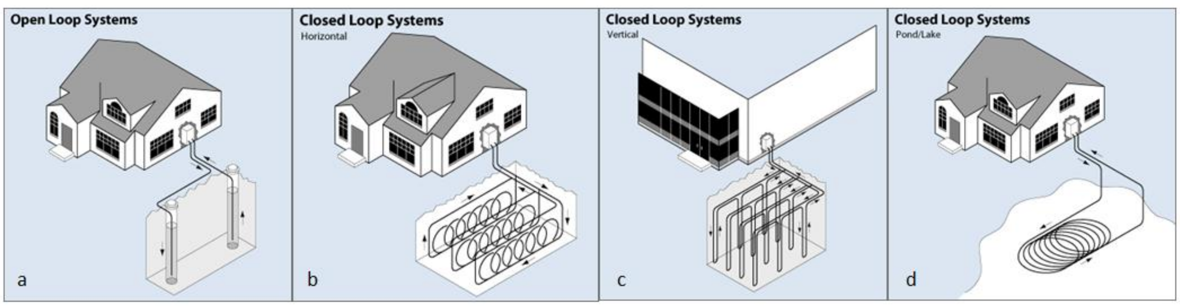


Figure 4: (a) Open loop, (b) closed loop horizontal, (c) closed loop vertical, (d) closed loop pond/lake geothermal systems (US DOE 2012)

3.2 Benefits of Using Geothermal as a Heating/Cooling System

In order to fundamentally shift the energy footprint of home heating and cooling from conventional systems that primarily rely on fossil fuel production to a more environmentally friendly solution, a mass implementation of a new technology fueled by a new resource is required. The national energy footprint has an opportunity to tap a resource that currently produces more than four times the amount of power consumed on the global economy (Barbier 2002). Figure 5 shows the energy savings possible if geothermal or ground source heat pump systems were used throughout the United States. There is great potential in all regions for energy reduction.

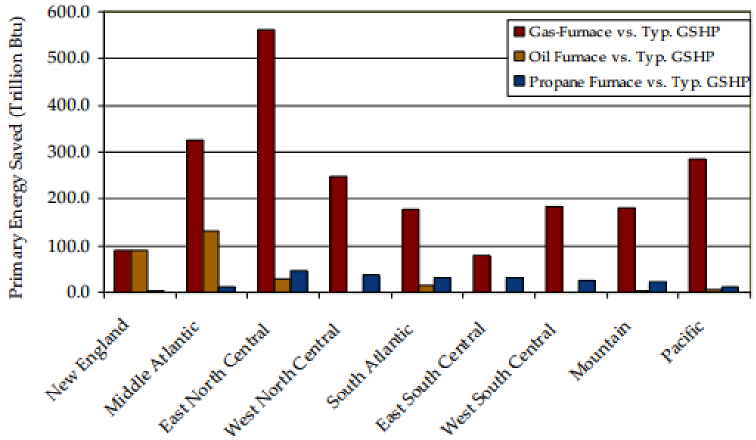


Figure 5: Energy offset potential using geothermal throughout U.S. (William Goetzler 2009)

One advantage to geothermal that makes it appealing to use in any location is that it poses the fewest constraints on the design of the house. For instance, the home does not need to face a certain direction, be designed a specific way, have a clear view of the sun, have access to a combustible fuel source, or require a backup system. This allows for a housing community to be built with geothermal heating/cooling virtually anywhere. It can be implemented in communities that are located in heavily wooded areas or communities that have no trees. Eliminating these constraints on buyers and builders as to where they can build, how the house must look, and what direction they must face makes geothermal a great option that can appeal to anyone that would otherwise purchase a conventional system.

Some of the other benefits of geothermal heating and cooling include a long useable life (20-25 years (Geothermal Genius 2013)) for the heat pump, since it is fully contained indoors. The underground loop system will last for 50 years or longer (Geothermal Genius 2013). The heat pump is analogous to a furnace and will be the only portion of the system that should require replacement. Geothermal systems also do not burn a fuel thus eliminating any chances of carbon monoxide poisoning. They also operate quietly and since there is no outdoor portion of the unit, unlike conventional systems, there is no noise to distract from outdoor activities. They can also have coefficients of performance of up to four, meaning that for each unit of energy put into the heat pump, you get four units of heat out since the "fuel" that they use (the constant temperature beneath the Earth's surface) is endlessly free (Geothermal Genius 2013).

Potentially the only downside to geothermal systems is that their upfront cost is higher than conventional systems. This is due to the labor required to install the loop field as well as the higher cost of the heat pump. However, there is some relief for this extra cost in the form of a government tax credit that is available until December 31, 2016. This tax credit will reimburse the buyer 30% of the cost of the system plus installation with no upper limit (Energy Star 2013). The cost of the full system is very specific to the application and will vary widely based on the house, contractor, and equipment purchased. For an average home, the high end of the rough cost of conventional forced air with air conditioning is around $13,000 ($8,000 for the furnace and $5,000 for the air conditioner) and for a geothermal system it is about $26,000 (Wright 2013). It was difficult to find cost information for both of the systems, but the rule of thumb is that geothermal costs twice that of conventional and the figures provided in this reference correspond to this. Applying the government tax credit of 30% (available until the end of 2016) brings the geothermal cost to $18,200.

Performing a net present value analysis of conventional forced air versus geothermal with variable conventional system heating and cooling costs yields Figure 6. The discount rate used for this analysis is 6%. Since the geothermal heat pump has a life of 20-25 years, forced air furnaces about 20-25 and an air conditioning units 12-15 years (Coleman 2013), it made sense to perform this analysis over 25 years, which would yield one replacement of the air conditioner at the 12 year mark. The expected level of utility savings also varies based on the system, so different savings levels were evaluated. As can be seen from the figure, the higher the monthly utility costs are with a conventional system and the more energy saved, the better a geothermal system looks from a net present value perspective.

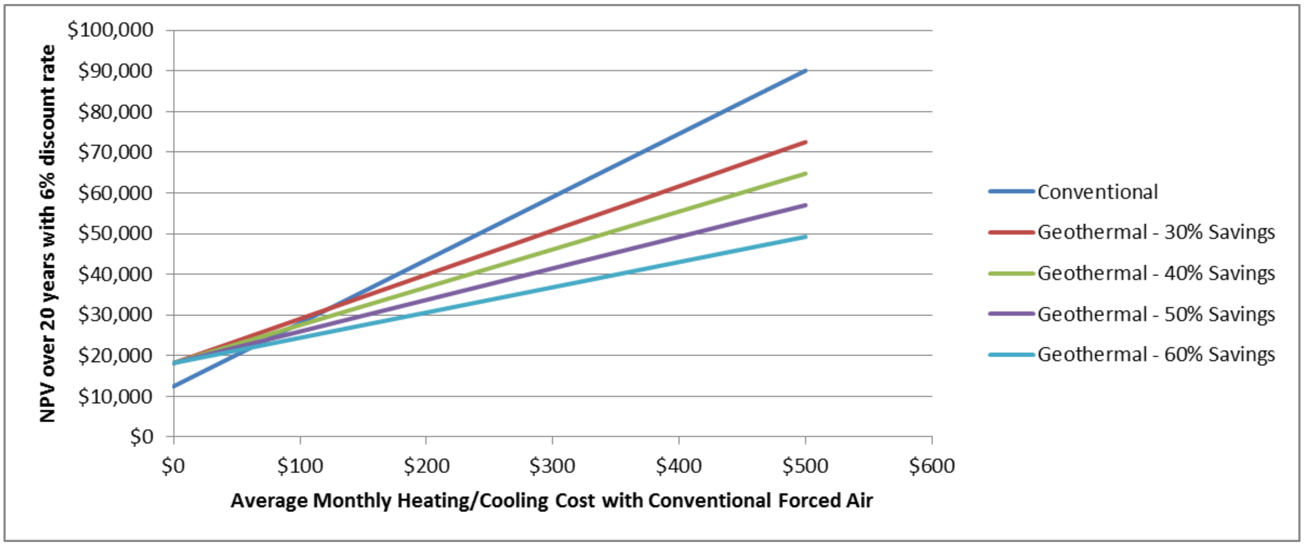


Figure 6: Net present value analysis of conventional vs. geothermal heating and cooling systems

3.3 The Chasm

The characterization of making the jump from early technology adopters to the mainstream is often the singular point in a product's life that defines when it is sure to be a success or a failure. Unfortunately, this time is often the most difficult point to pass. As illustrated below, the jump between early adoption and mainstream use is the difference between being on the side that never gets past the niche market and the side that will eventually become a successful product. This "chasm" is the point that needs to be passed in order to transform the home heating market away from petroleum based products.

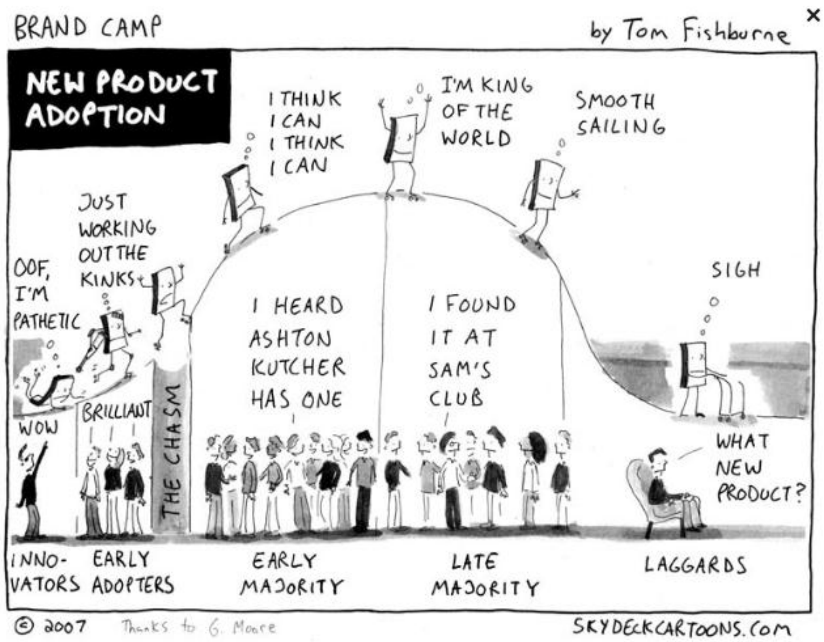


Figure 7: New product adoption (Fishburne 2007)

A Department of Energy study concluded after review that the prediction of market penetration (for new technology) could be estimated by the relation to the product's payback period over its preceding technology. In this study (captured in the figure below), the concluded opinion was that with persistent introduction, every technology would have to achieve a payback of 5 years to capture at least ten percent of the population (William Goetzler 2009). This was considered the threshold of going from a niche product to mass implementation. This is the chasm.

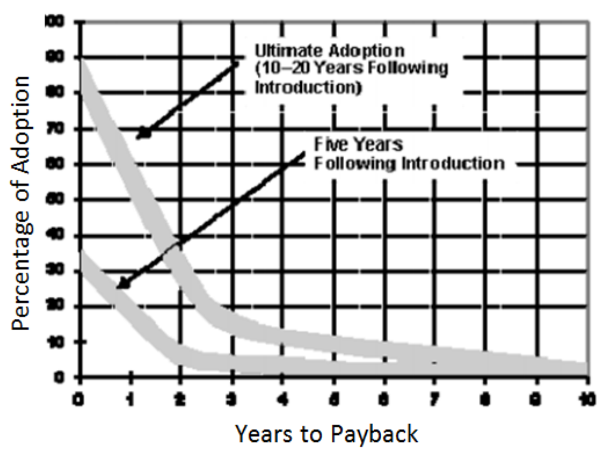


Figure 8: Correlation of payback period to market penetration (William Goetzler 2009)

3.3.1 Barriers to Market (for the consumer)

In addition to payback for the technology, it is reasonable to assume that other factors impact the market adoption of new technology. This includes:

- Initial capital cost
- Confidence in quality (i.e. brand recognition)
- Quality guarantees
- Performance
- Disruption from installation
- Image (aesthetics)

These issues will have to be addressed, quantified and resolved in order to improve market penetration. For capital cost, data will have to be gathered to determine the customer threshold (independent of payback). For confidence and quality, it will be necessary to determine the authority that most easily sways opinion. Disruption from installation and image are dependent on the technology used and when it is installed (during the life of the house).

3.3.2 Barriers to Market – Technical

In addition to consumer sentiment, the limitations in technology and implementation may also drive concerns (William Goetzler 2009). These include:

- Geological limitations in certain areas
- Cost of site evaluations (for compliance)
- Designs are not typically "cookie cutter" for all sites
- Degradation of system is high if installation is poor
- Retrofit applications are expensive

These barriers do not represent technical limitations based upon new design, but rather implementation. For this reason, the key solution to technical barriers will need to address the method of implementation.

3.4 Overcoming Barriers to Mass Market

The barriers that challenge the implementation of geothermal heating and cooling all have reasonable solutions or paths to solutions. From consumer barriers, the key issues that challenge mass implementation are payback, capital cost, quality, and disruption for installation. For technical barriers the key challenges are cost of installation, consistency of quality and time of implementation.

3.4.1 Overcoming Payback and Cost Challenges

As shown previously, the cost of geothermal systems are initially higher than conventional systems but through utility savings they eventually become beneficial. In order to improve capital cost and payback, the size of the system will need to be evaluated for optimal sizing. The figure below compares the performance of GSHP sites around the nation to a conventional fuel source of comparable size. As seen in the figure below, of the 250 sites surveyed nearly all systems saw paybacks around the threshold suggested of five years. This confirms what was said earlier that, while the capital cost is higher the overall system cost for the life of the product will be an improvement for the consumer. Current residential natural gas users will see a return of investment from installing a geothermal system within approximately 11.5 years, while commercial natural gas user would see a return in less than four years. As the system sizes grew, this payback shrunk, most importantly with natural gas (as this is the most prevailing fossil fuel used in home heating) (Paul Lienau 1995). From this data it seems that in order to improve payback larger systems will be needed.

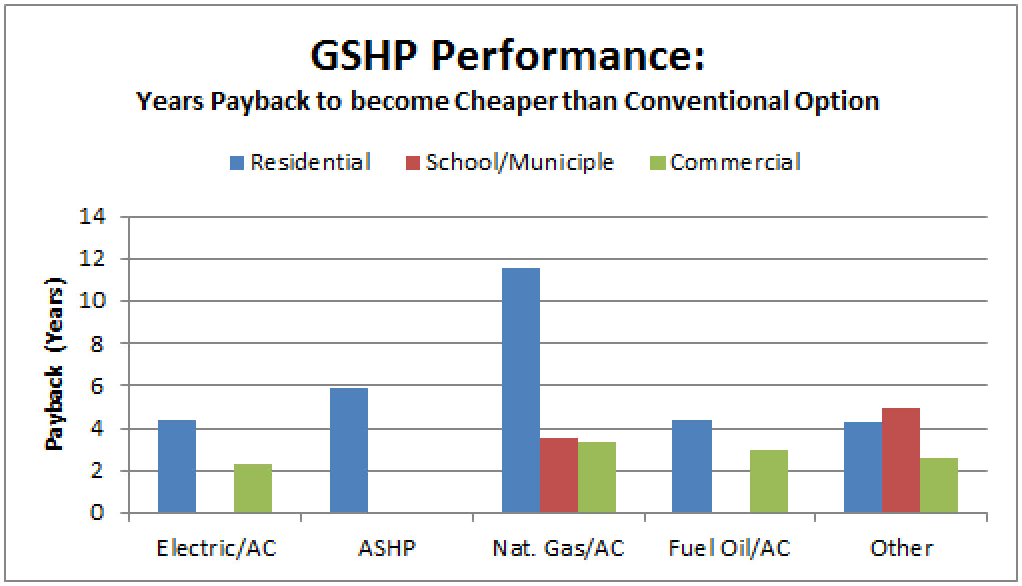


Figure 9: Average payback period for different sized systems (Paul Lienau 1995)

With respect to the upfront capital cost, many homeowners are not financially able to support an installation due to the lack of liquid funds available. In the case of new housing this is easily resolved by including the upfront cost in the mortgage; yet even with this, the homeowner must commit a large sum of money in loan to pay for this system. A possible solution to this may be installing systems for multiple homeowners to share. The largest cost parameter of GSHP systems is the ground pipes (Paul Lienau 1995). If larger systems were built for multiple homes, the action of installing ground pipes—whether for community use or singular home use would be diminished as the cost of surveying, site construction labor, shipping and logistics would be shared by multiple participants. At this time, calculable figures cannot be determined until a more finite solution is chosen. This concept will warrant further investigation to determine the possible impact.

3.4.2 Overcoming Quality and Time of Implementation

The challenge of quality and disruption to install is one of the biggest challenges that face mainstream adoption that are tolerated by the early adopters. In order to overcome this challenge, the time of implementation will have to be focused in order to suit the installer (for favorable conditions of install) and also suit the consumer (who does not want to be disrupted). The best solution for this is to install the system at the time of build. With larger systems also being used, this would complement the conditions by allowing shared costs of events associated with home building as well as GSHP installation. This includes site surveying, layout, material, labor and even capital to build. As well, by incorporating the system at this point, the consumer will perceive confidence in the product from the home builder, will not feel vulnerable to problems as the entire community has the system, and will also enjoy the fact that the neighborhood was designed to accommodate the system.

3.4.3 Challenges and Further Investigation

Further work is needed to quantify the specifics of cost optimization for the consumer. Since this technology is far too expensive to consider for mainstream adoption in old homes, our efforts will focus on its implementation in new housing developments and ways to reduce the cost of the system. In the new housing segment, it will ultimately be the builders that will have the most influence on whether geothermal systems are implemented in their developments. The homeowner is obviously an important stakeholder as well, but if geothermal is not offered to them as the only option, then they will be unlikely to adopt it.

4 Design Ethnography

The purpose of design ethnography is to create a living profile that can be used as a tool to develop answers about design direction later. This profile is a growing persona that will include obvious as well as nonobvious information that has to be gathered. Most of the most critical components of the persona will come from information that may not even be obvious to the target user.

4.1 Developing the Design Ethnography

Developing the ethnography requires five basic steps to create an exhaustive profile. The profile must include guidelines that focus the intent of the persona, clear establishment of each participant's role in the product use, clear understanding of the current situation and information at hand, a strategy to learn more information where it is lacking via various learning tools and a method to filter through this data and ultimately extract meaningful data to build the profile. This is described further below.

4.1.1 Framing Guidelines for Research

In order to define and illustrate the persona of this proposal it is important to define our objective of data finding. Looking at needs for home energy use it is clear that our first priority is to establish a significant basis for an area of study. As covered in the previous section, home energy heating and cooling comprises a large share of an energy resource that is limited and degrading to the environment. From current knowledge we had also learned that of the numerous options there are to circumvent fossil fuels for home heating, geothermal is the only option that provides a significant shift away from the utilities and introduces a new market for energy. It is understood that these systems can be made reliably and—after a certain period—cost competitive with conventional systems. Our data gathering at this point will be focused on establishing more information to move from the niche market to the main stream and what hurdles lay ahead.

4.1.2 The Who

In order to understand what it takes to go from early adoption to mainstream we must understand the mechanisms that drive the mainstream system currently in place. To do this we will have to become aware of not only the end user home owner, but also the manufacturers of current technology and facilitators (i.e. home builders). From this we will target our information accordingly:

- **Users:** This is comprised of both the home builder who provides the product to the homeowners as well as the home owner. The home builder will be the person to convince that the technology is economically viable for them and not a liability. The homeowner will be the person to understand in order to help the home builder execute the implementation in a method that is attractive and appealing to the homeowner.

- **Stakeholders:** Manufacturers, home builders and homeowners all comprise the stakeholder definition. Home builders and current manufacturers are invested economically, while home owners are invested both economically but also with regards to utilization.
- **Experts:** The experts of home heating and cooling will be the academic background surrounding the industry, the manufacturers of current technology, geothermal systems as well as the home builder. This comprises a concept/design/implementation perspective of the product use.
- **The Client:** Ultimately, the home builder is the biggest priority for reaching approval. Understanding the singular point that the home builder goes from skeptic to adopter is the jump from niche markets to mainstream.

4.1.3 Using Existing Knowledge

Most of the information we have with regards to the home energy market can be found from local contractors, academic studies and DOE models and reports. From the information we found, it seems there is a clear dependence on fuels for home heating and that this energy is significant to the national energy footprint. Of all of the methods to possibly displace fossil fuels, solar and geothermal methods are the best options. GSHPs appear to have the most practicality robustness with regards to applying anywhere in the nation (or even worldwide).

4.1.4 Learning Methods

The best methods for observation will be dependent on which user is being targeted. For manufacturers, there is probably little depth to what motivates them other than demand. For home builders it will be necessary to understand how they interact with the product on a daily basis as well as how they comprehend and understand new technology in home building. Homeowners will be require more intrusive data gathering that picks up on the non-obvious options and perceptions about using new technology. The homeowner’s perception about cost savings is probably well enough understood to warrant intrusive data gathering.

- **Observation:** Data gathering for home usage, statistical information and cost comparison will be sufficient.
- **Surveying:** Surveying will be an easy way to gather information that is non-intrusive from users including home usage, and current technology and implementation.
- **Interviews:** Develop and understand the social aspects of our stakeholders. What drives them to make decisions? This is also true for the client. In this case, this means finding out why the home builder builds houses the way he or she does and what motivates them to integrate new technology.

4.1.5 Data Management and Gathering

Current surveying and interviews have been gathered from the home owner with respects to their user role and minor stakeholder role. Further information will be needed about the home builder in the future, however at this point of data gathering it was not clear—as it is now—how much of an authority the home builder presents. Surveying results conclude that most people do see their home heating and cooling as a major energy factor of their lives. Interviews reveal that most people do not have strong feelings or opinions about their systems and are more likely to accept what is given to them rather than seek out alternatives. This would make the homebuilder the primary stakeholder and not the home owner.

4.2 Observation/Surveying

As a derivative of the energy log done in previous work, homeowners were asked to review their energy use and describe a nominal day at different times of the year. They were asked to rate their activities by how much energy they thought it consumed as part of their daily consumption. The conclusions were then tabulated and sorted by category. One of the results, as seen in the figure below, suggest that most people do see home heating and cooling as a major energy user in their life at on average 22%. The only category that was higher was transportation.

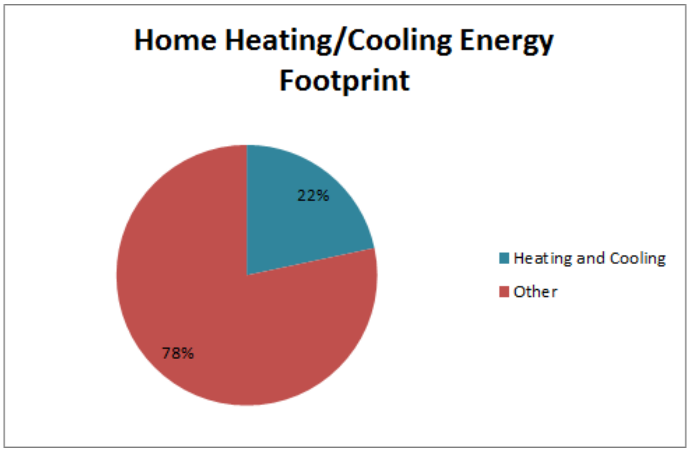


Figure 10: Survey of Individuals Regarding Perception of Energy Use

4.3 Interviews

Interviews have been conducted with potential home buyers as well as home builders. The purpose of this was to first understand what motivates a home buyer when looking for a home, and then to find out why home builders do not offer more options to their customers in the way of energy improvement. These results are captured below.

4.3.1 Interviews with the Home Buyer

Interviews were conducted in order to find more information about consumer perception for individuals. For this initial interview, the premise was to find out how they fit into the hierarchy of decision-making in their household and then qualitatively review their perception of their home heating system. The aspects of their interaction with it were addressed as well.

The results of the interview suggest that regardless of demographics, all individuals did not see selecting an ideal heating and cooling system as part of their process of looking at new homes. As well, there appeared to be little background knowledge with regards to different options available. One speculation that will warrant further review is that home owners, as users, see the home builder in the expert and primary stakeholder role. If this is the case, the majority of stakeholder appeal will not be with the homeowner but rather the home builder. The sample interview can be found in Appendix 3.

4.3.2 Interviews with the Home Builder

Reviewing project concerns it was apparent that the key stakeholder who would need further understanding was the home builder. The home builder is the stakeholder who will be establishing for the homeowner what is main stream for home design and facilitate what can be done. In this way, the home builder actually has equity as an expert for the home buyer to reference. An interview was conducted to determine the nonobvious opinions and views of the homebuilder as well as understand the systematic structure that leads them to make their choices today. This interview is captured in Appendix 3**.**

The overall opinion of the homebuilders interviewed is that they are not interested in providing options to customers that deviate from a stock house plan. When asked what is important, they suggest that providing the customer with the lowest cost and highest quality furnace is their motive. The capability to install is not significant to them as they contract this work to a third party contractor. Product selection is based primarily on quality rating and price. The purchaser of goods and supplies at the home building company is the primary selector of what products are installed. His or her opinion of what to install is based on the fact that a standard system will have a consistent fee for installation by the third party contractor, so as long as the product is common, affordable and reliable there is no motivation to change.

Diving into the nonobvious answers, it seems that most home builders know that they are competing against other home builders for price and quality. They are not interested in giving their customers higher priced options or large deviations from standard build plans because all of this costs much more than a "plug and play" house plan and could hurt their bottom line. As well, any chance to deviate is a potential to introduce a new problem to their work flow. Building the same thing over and over again is preferred because it has predictable outcomes. New technology has risk of disappointing the home buyer—even when the home buyer wants said technology.

4.3.3 The Conundrum

The results of further investigation led to a conundrum about the motivation of the stakeholders. The key stakeholder continues to be the home builder as they are seen as the gateway to the home buying base. Their motivation—understandably—is to protect their profitability by providing the best quality, lowest cost house design that meets the needs of the largest consumer base. The paradox here is that until the mainstream demand becomes aligned with geothermal systems, there is no incentive for the home builder to consider it and until the home builders can readily implement it there is no easy way to make the jump from early adoption to mainstream—hence the key persona to change is not the home builder at this time.

4.3.4 Interviews with the City Manager

After interviewing home builders, it seemed more information was needed about policies that could have influence on the home builder to solve the conundrum. Due to time constraints, only one city manager was found to interview. In this case, the former city manager—now associate for the State of Michigan—has extensive experience with smaller towns implementing their own facilities to solve financial distress or environmental issues. Such was the case in Grand Blanc, MI where a water filtering system was installed, owned and operated by the city in order to provide better quality water. Further discussion revealed that in many other circumstances, local municipalities have participated (or had the opportunity to participate) in commercial ventures for the sake of either creating local revenue, improving welfare of the public or conserving natural landscapes. The major pitfalls uncovered were the availability of equity or funding at the local level to provide such participation. Currently, the most feasible options to implement infrastructure reform remain grant funding at the state and federal level.

4.3.5 Impacts to the Persona

The new data gathered have taken the stakeholder roles to new territory. At first, it appeared that the home builder was a feasible stakeholder to establish a strategy with to address sustainable design. After learning more about the needs and strategies of the home builder, it then seemed clear that a new stakeholder would have to be introduced to provide leverage with the home builder. In this case that was government influence. This was strategized at the local level as the investment would be localized to municipalities and the capital cost would be on the same order of magnitude as other city projects. Further research showed that municipalities have and do participate at municipal level utilities and projects, making the possibility of a city funded project a reality.

5 Description of Persona: Municipal Leader

As stated previously, the resultant persona that provides the most capability for change—along with potential desire—is in fact municipal leadership. Positions such as city planners and city managers are the ideal point of position to champion this solution as they are involved in the day-to-day business of the city operations and/or are regarded as authority figures entrusted with maintaining fiscal balance of operational costs. As well, city planners are entrusted to guide the city along a path that serves the community as well as city governance best. As noted, other projects that would require the raising of funds, authorization of change and direct facilitation such as public water works projects or other civil causes would be championed by this position. Therefore, there is no reason to suspect another person would be better suited.

The needs of the persona are established in a twofold problem in municipal governance: insufficient revenue sources for municipal operations and facilities modernization to reduce operational cost. Currently throughout the State of Michigan, there are a growing number of local governments that are facing revenue shortages to meet the growing costs of operating. With property taxes mostly stagnant and few upcoming and growing industries, there are few places to turn for additional revenue. By reviewing the possibilities of a locally run utility, the city stands to acquire a modest revenue stream that can deviate the profit margins away from larger corporate entities directly into the balance sheet of the local government. In addition to this new revenue stream, municipalities also have an option to look at how they can update their own systems to reduce costs. Through both of these topics, there is a solution to a growing problem in local governments.

6 Requirements and Specifications

In order for geothermal heating and cooling systems to be used more thoroughly in new construction residential housing, they must be able to satisfy certain requirements for both home builders and homebuyers. The customer requirements and product specifications are summarized in Table 1 and described in more detail in sections 6.1 and 6.2.

Customer Requirement	Product Specification	Target
Cost Effective	Total System Cost	<$13,000
Provide Monthly Cost Savings	Payback Period	<5 years
Long Lifetime	Lifetime of Indoor System	>20 years
Long Lifetime	Lifetime of Outdoor System	>100 years
Year Round Comfort	Heating and Cooling Capability	Equiv to conventional
Reliability	Issues per Year	< Conventional
Optional for New Construction	% of homes in community w/ geothermal systems	100%
Not derived from customer	Reduction of Materials Usage over Baseline	< Conventional
Not derived from customer	Reduction in Emissions over Baseline	< Conventional

Table 1: Customer requirements and product specifications summary

6.1 Customer Requirements

From our ethnographic research as well as data gathered from various resources, we have come up with the following customer requirements that a geothermal system must satisfy. These requirements come from our major stakeholder, the builder, and our other stakeholder, the home buyer.

Cost Effective: From our research, it is apparent that one of the major barriers to mass implementation of geothermal is the cost. A typical single home geothermal system for an average sized home (including both indoor and outdoor components) costs about double what a conventional system would cost for the same home. Even after applying the 30% tax incentive currently available, the geothermal system is still approximately 40% more expensive than the conventional system. For this reason, cost effectiveness is a major requirement for our product.

Provide Monthly Cost Savings: In order to justify the high initial cost, it is important that the geothermal system saves enough energy to allow for a positive cash flow and eventual payback of the initial investment. Since our research showed that typical home buyers and homeowners do not have much of a preference on which type of system they have, it is necessary that geothermal pose the benefit of reduced utility bills in order to make up for the additional cost.

Long Lifetime: In order to be competitive with conventional systems, geothermal systems must last as long or longer. Homeowners do not plan to replace their furnace or air conditioning regularly and would not adopt a geothermal system if it did not have the same lifetime.

Year Round Comfort: Since conventional heating and cooling systems have been proven to keep homes conditioned to comfortable temperatures year round, geothermal systems must also do the same. It would be unacceptable for the geothermal system to leave the home too hot in the summer or too cold in the winter even on the most extreme days.

Reliable: Another finding from homeowners and builders is that home buyers want systems that are reliable. They don't have a particular preference on the type of system they have, but they require it to be a reliable system. Since it keeps their families comfortable in their home, having an unreliable system is not an option. Conventional systems have been proven to be reliable, so geothermal systems must do the same.

Optional for New Construction: Our research shows that homebuyers will take whichever heating and cooling system is offered to them and will not go out of their way to explore other alternatives. This showed us that the home builder was our primary stakeholder, so it is up to them to make geothermal an option and educate home buyers that rolling the additional upfront cost into their mortgage will pay off in the long run.

6.2 Product Specifications

In order to analyze whether or not the geothermal system can satisfy the needs of the customer, the requirements must be turned into engineering specifications so they can be measured.

Total System Cost: The geothermal system has two major components - the unit that resides inside the house and the loop system outside the house. While the total cost of both systems is being considered for the specification, it needs to be split up into two parts due to the consideration of community systems which would involve different loop systems than a standard geothermal system. The indoor portion of the system involves the heat pump which adds heat to or removes heat from the working fluid. The indoor system cost is directly dependent on the size of the home (i.e. size of the unit), but cannot be directly related to either a furnace or an air conditioner. The outdoor portion of the geothermal system consists of the loop which exchanges heat with the ground. The orientation of the loop will vary greatly between single home systems and community systems, so it is necessary to separate it from the cost of the full system. While the indoor and outdoor portions of the system will be considered separately in our analysis of each concept, the total system cost is what homebuyers and builders will care about, so the target for this will be to cost less than or equal to a conventional system, which as discussed in section 3.2, is around $13,000 for an average sized home.

Payback Period: If the cost of the geothermal system ends up being more than a conventional system, then it is necessary that there are utility cost savings over a conventional system. Since our research shows that home buyers do not want to pay more for their heating and cooling system unless it makes economic sense, there must be monthly utility savings. Based on a Department of Energy study discussed earlier, the payback period for a new technology must be 5 years or less in order to go from being a niche product to mass implementation. Since the cost savings will vary greatly based on the size of the home and the conventional system that is being avoided, the target for this specification will be a payback period of 5 years or less.

Lifetime of Indoor System: In order to replace a conventional heating and cooling system, the geothermal system must have a similar lifetime. Home buyers would not tolerate replacing a geothermal system more often than they would need to replace a conventional system. Therefore, the target for the lifetime of the indoor portion of the geothermal system, the heat pump, is 20 years or more.

Lifetime of Outdoor System: If the outdoor portion of the geothermal system was to fail, then it would be much more involved to replace than the indoor portion. The outdoor portion would involve excavation and would be very labor intensive. Essentially, the outdoor portion should not need to be replaced, so the specification for the life of the outdoor portion is greater than 100 years.

Heating and Cooling Capability: In order the keep the home as comfortable as a conventional system throughout the winter and summer months, it must have sufficient heating and cooling capacity. This is dependent on the size of the system, but the effectiveness of the loop system will also play a factor in the heating capacity. In order to simplify this specification, the target will be equivalent to the conventional system.

Issues per Year: The reliability of the system was something that is very important to the primary stakeholders, so the system must be at least as reliable as a conventional system. Reliability can be quantified as the number of issues that are had with the system per year. While we could not find a reference for how many issues per year conventional systems experience on average, the target for the geothermal system will be less than or equal to the number of issues a conventional system experiences.

Percentage of Homes in Community Being Built with Geothermal: Having a geothermal system as an option when building a new home is essential in order to encourage buyers to adopt it. The target for this is the percentage of homes in the new housing community being built with geothermal systems. If a community geothermal system were to be implemented in a new housing development, then all of the homes would have to utilize geothermal. The goal for this is 100%, or full implementation of geothermal in a new community. Our research shows that home buyers will tend to go with what is the cheapest, most proven, and most familiar system. If the builder predetermines that all of the houses in the development will utilize geothermal heating and cooling, then home buyers will be much more likely to adopt the system.

Reduction of Materials Usage over Baseline: From our lifecycle assessment research on the conventional system, a requirement of a new concept is to reduce materials usage. This specification was not developed from a customer requirement, but was an outcome from our research and is important to focus on so that the proposed concept has a lower environmental impact. A conventional system has two separate components, the furnace and air conditioning units. The relative size of these units does not change drastically with the size of the home, so the target for this specification will be less materials usage than conventional. It should be noted that this specification was not derived from any customer requirements as none of our research has indicated any concern of materials usage from the stakeholders.

Reduction in Emissions over Baseline: This is another specification that was conceived from our lifecycle research. The emissions given off during the use phase of a conventional system vary based on the area. For example, the electricity used by the system is generated using different means depending on where the unit is installed. It also uses different amounts of fuel based on the climate. These emissions also depend on the size of the unit installed and the use conditions. The target for this specification will be less than the conventional system. It should also be noted that this specification was not derived from a customer requirement. Home builders or home buyers did not show any interest in reducing emissions. However, this would potentially be needed in order to gain grant, financing or tax incentives from local, state or federal government sources. Reduction in emissions would need to be significant and long-lasting.

6.3 Determination of Most Important Specification

To help determine which specifications should receive the most attention, a quality function deployment (QFD) was used. This tool allowed us to weigh the relative importance of each customer requirement and rate their correlation to the specifications to determine the weighting of each specification. Not surprisingly, this told us that the total system cost as well as the monthly savings was the most important specifications to focus on. Issues per year and percentage of homes in the community with geothermal were also important. These findings agree with our research that home buyers want affordable systems that are reliable and will usually take whatever is offered to them from the builder. The results of the QFD can be seen in Appendix 6.

7 Sustainability Evaluation

This section will give an overview of the first steps of the process outlined in the "Environmental Improvement Through Product Development" guide (Tim McAloone n.d.). The first step of this process involves the use context of the product. The next step is to create an overview of the environmental impacts of the product. The third step in this process is to organize the findings from step 2 into categories based on materials, energy, chemicals, and other types of environmental impacts. The fourth step in the process is to identify the stakeholder network.

7.1 Use Context

This product is a geothermal heating and cooling system capable of servicing multiple dwellings in a housing development. This product needs to be capable of using the geothermal energy of the Earth to transfer heat to or from a series of tubes buried underground. This fluid then must be pumped in and out of individual dwellings in which energy from the ground is either added to or removed from the air that is circulating throughout the home. In the winter months, when heating is needed, the fluid flowing through the series of tubes needs to gain energy (or be heated by) the warmer temperature of the underground soil. This warmer fluid will then lose heat to the home and return to the ground to be warmed again. In the summer, this process will be the opposite. The fluid flowing through the series of tubes needs to lose heat to the cooler soil beneath the ground. This cooled fluid will then gain heat from the air in the home and displaces this heat into the ground. In the case that geothermal power is not enough to heat or cool the home, the system must use electrically powered heating or cooling to compensate for the difference in performance. The indoor component of the geothermal systems should have a lifespan of 20 years or more (Geothermal Genius 2013) and the life of the outdoor component must last for longer than 50 years, ideally for the life of the home. This system will be designed to be installed in new housing developments, so its target customer is a new home buyer. However, as discussed previously the builder has the most say in choosing the system. The target use area will be climates where sufficient heating or cooling is needed for a large portion of the year. Michigan is a climate in which this is the case, so it will serve as a potential usage location for a pilot community.

7.2 Environmental Impacts Overview

Environmental impacts are identified during the phases of the product lifecycle including raw materials, manufacturing, transportation, usage, and disposal. Table 4 in Appendix 2 lists these areas and the potential impacts. Issues with production of plastic tubing for the loop system were found to be significant. Production of this tubing was not initially thought to be a concern, but it certainly warrants some attention. The use phase has the lowest impact as there is not any direct waste that is produced by the product.

7.3 Environmental Impact Profile

Table 5 in Appendix 2 organizes the potential impacts from Table 4 into materials, energy, chemical, and others categories. Organizing the environmental impacts this way makes it easy to see whether most of the impacts are from the materials needed to build the product, from chemicals produced in the production process, from the energy needed throughout the product lifecycle, or from other sources. From this organization, it seems that the area of most concern is with chemicals. There are a few components of geothermal systems that have undesired side effects, such as the production or disposal of the loop tubing.

7.4 Stakeholder Network

All parties that interact in some way with the product have been identified. In this case, it would be the manufacturer of the geothermal loop tubing, the manufacturer of the heat pump, suppliers of raw materials, the shipping companies that distribute the product, the developer of the community, the supplier/installer of the system, the homeowners of the community, and the scrap company that disposes of the product or its components when they have reached the end of their usable life. These interactions are described in Table 6 in Appendix 2. The downstream stakeholder has the ability to influence change and reduce the environmental impact of the product from the upstream stakeholder. For instance, the supplier of the geothermal system can insist that the geothermal loop materials purchased are made using low impact manufacturing techniques. This shows that the stakeholder with the greatest leverage in getting the geothermal system from concept to implementation is the community developer. Most new homeowners tend to adopt whichever heating/cooling system the developer has chosen for the majority of the homes in the development. If the developer chooses to install conventional systems, then all of the buyers will purchase conventional systems. In order to get geothermal heating and cooling more recognition, the developer has the power to make the choice to only sell homes with geothermal systems installed. The more geothermal systems that the developer installs, the more homeowners and friends of homeowners will experience geothermal heating and cooling.

8 Environmental and Social Impacts of the Baseline

This section describes the environmental and social aspects of our baseline system, a natural gas or propane forced air furnace with electric powered air conditioning.

8.1 Reason for the Baseline

The US DOE estimates that almost every house in the U.S. has some form of space heating, and 76% of the homes have air conditioning. Natural gas forced air furnace systems are the most popular comprising 42% of the heating systems. About 70% of the households have central air-conditioning systems run by a conventional external condenser or heat pump (US DOE 2001). The goal is to determine how to improve heating and cooling of homes, so it is appropriate to have the most common system as the baseline. This is a worthwhile goal as the major proportion of the environmental impact of a residential building is due to the energy consumption for heating and cooling (G. Keolian 2000).

8.2 Applicability of the Lifecycle Study

A Life Cycle Assessment of residential heating and cooling was conducted under the auspices of the University of Pittsburg (V. Shah 2007) and applies the ISO 14040-1997 LCA framework as described by NSF International (ANSI/ISO 1997). The software used was SimaPro 5.0 (M. Goedkoop 2001). It accessed the Franklin USA 98 (Franklin Associates LTD. 1998) and the ETH-ESU96 (R. Frischknecht 2004) databases which represent average practice in the USA and Europe, respectively. The manufacture information was obtained from manufacturer's information, where available. The example hardware was from Carrier Corporation and Burnham Corporation. Operating energy consumption was calculated from the Home Energy Saver web interface to the DOE-2 simulation software developed by the US DOE (Lawrence Berkeley National Laboratory 2006). Insulation levels were based on recommendations of the International Energy Conservation Code (International Code Council 2000).

8.3 Study Parameters

An L-shaped two story house with 181 m^2 (1950 ft^2) of living space and a one car garage was selected, occupied by a family of two adults and two children. The house was simulated in four regions to capture differences in performance based on regional variability. Texas and Minnesota represent two extremes, predominately requiring cooling and heating, respectively. Oregon and Pennsylvania represented a less extreme amount of heating and cooling. Daily temperatures were obtained from the National Oceanic and Atmospheric Administration monthly station climate summaries (which are available in 2013) (National Oceanic and Atmospheric Administration 2007). The inclusion of these last two states allowed the additional analysis of electricity generation energy mixes. Oregon used 67% hydropower and other renewables in 2004, versus 2-5% for the other three.

Three energy systems were evaluated in the study: a) central natural gas furnace heating and conventional central air conditioning (our baseline), b) natural gas powered hydronic heating and conventional central air-conditioning, and c) electric air-air heat pump for heating as well as cooling (V. Shah 2007).

8.4 LCA Impact Assessment Conclusions

The impact assessment is detailed in Appendix 3. The major impacts are listed below.

1) The boiler and the AC system have the largest impacts associated with the appliances and distribution systems. The heat pump is the lowest. This is due to having two systems versus one for home heating and cooling. Therefore a strategy to reduce the materials used in systems may reduce impact due to metal extraction and manufacturing.

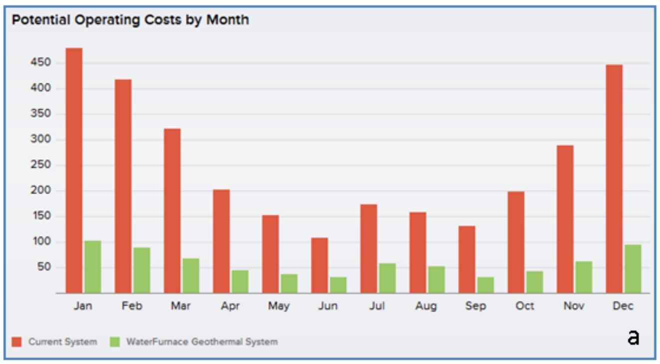
2) Operational energy consumption impact is dominant over the entire study period. Therefore a strategy to reduce energy use will reduce impact not only in Climate Change, but also in Resources and Human Health (respiratory organics). Ecosystem quality (aquatic toxicity) impact will also be reduced.

3) Regional impact differences are due to effects of varying heating and cooling needs, and the energy used to derive electricity in the region. Solutions that lower total energy needs are more likely to have a positive impact. Switching from one energy source (e.g. gas to electric) may or may not have a positive total impact.

8.5 Quantitative Impact of Baseline

While the above gives a general idea of the relative merits of geothermal heating versus other sources of heating, it does not give a quantitative comparison of heating systems for a single home that can be expanded to a multiple home residential community.

Commercial websites can give estimates of potential operating costs and carbon footprint for homes though it must be noted that such commercial websites have a vested interest to sell equipment and may not be unbiased. An example is the Water Furnace site (Water Furnace 2010). One of our team members has a water furnace installed in their current house. In order to assess the credibility of the Water Furnace calculators, we plugged in the location, square footages, etc. of their house into this calculator and compared the results to their actual bills over the last twelve months. Figure 11a was generated from the Water Furnace website. The "Current System" dataset is the theoretical propane usage of our team member's home and the "Water Furnace Geothermal System" dataset is the theoretical geothermal system usage of our team member's home. Figure 11b is the actual usage of our team members home. As can be seen, the estimated geothermal usage and the actual geothermal usage match fairly well considering the actual system installed in the home is almost 20 years old.



Beginning Date	End Date	Year	KWH	$
16-Oct	14-Nov	2012	958	85
14-Nov	17-Dec	2012	1262	112
17-Dec	17-Jan	2013	1660	144
17-Jan	19-Feb	2013	1994	170
19-Feb	19-Mar	2013	1484	132
19-Mar	17-Apr	2013	1283	118
17-Apr	16-May	2013	801	78
16-May	19-Jun	2013	699	82
19-Jun	18-Jul	2013	503	57
18-Jul	19-Aug	2013	633	69
19-Aug	17-Sep	2013	503	58
17-Sep	16-Oct	2013	537	50
	Total Energy and Costs		12317	1155
b	Total Carbon Emissions		16098.32 lbs CO_2	

Figure 11: (a) Calculated operating costs from Water Furnace website calculator (b) Actual bills from team member's home

The sum of the green bars in the graph amounts to a theoretical geothermal cost of \$750. This compares to the actual cost of geothermal in the home at \$1,155 (or 54% higher). As the actual cost of geothermal is for a home built 17 years ago, it is possible that new geothermal systems are much more efficient, so the results from the calculator seem reasonable and this allows us to compare the costs between geothermal systems and conventional forced air systems. In order to verify this calculator, the propane usage and the emissions must be verified as well.

The sum of the red bars in the graph totals \$3050, which is the theoretical estimate of propane heating and electric air conditioning for this 2400 square foot house example. Another website estimates that a 2000 square foot house in Michigan would use 907 gallons of propane to heat the home (Munson n.d.). At \$3.11/gallon (Commonwealth of Massachusetts 2013) this is \$2821 per year. The national average electric usage for heating and cooling is approximately 6000 kWh's per year (US EIA 2013). The cost of this electricity is \$726 using a national average of \$0.121/kWh (US EIA 2013). The total cost of propane and electric is \$3,547 per year. This is only \$500 different from what the calculator predicts, so we can conclude that the calculator is fairly accurate for predicting the usage costs for each system.

The emissions predicted by the calculator are 20,500 pounds of CO_2 for a 2400 square foot home using propane and 4,000 pounds of CO_2 for a 2400 square foot home using a geothermal system. Using the figure collected of 907 gallons of propane to heat a home and 6,000 kWh's to heat and cool a home, the carbon emissions come out to about 19,000 pounds of CO_2. Using the actual data from our team member's geothermal home, the carbon emissions come out to 16,100 pounds of CO_2 (US EPA 2012). The carbon emissions from the Water Furnace calculator and the calculated emissions for a propane system match very closely (20,500 vs. 19,000 pounds of CO_2). The carbon emissions from the Water

Furnace calculator and the calculated emissions for our team member's home do not match (4,000 vs. 16,100 pounds of CO_2). Correcting the electricity usage of our team member's 17 year old system to match the lower usage of the system from the Water Furnace calculator, the carbon emission of our team members home would be 10,400 pounds of CO_2 per year. This number is still much higher than the calculated number, so the Water Furnace calculator would need to be investigated further to see how they are calculating carbon emissions. Either way, the carbon emissions from a geothermal system are around 50% of or lower than the emissions using a conventional forced air system and the yearly heating and cooling costs are over 50% lower.

8.6 Social Impacts of Baseline

The petroleum industry provides jobs in well drilling, refining and delivery. This work is not distributed evenly across the country, so the local impact on communities including jobs and urban blight is uneven and may raise equity concerns.

9 Concept Generation

Changing the region's approach to home heating could be started numerous ways—many of which would likely fail if not evaluated with the information gathered. From the personas identified, and the current information known about alternative systems the expected requirements to transform the technology from early adoption to mainstream implementation is clear. The proposed plan of action must give the home owner no extra burden in capital expense as well as provide a safe and reliable form of heating and cooling. The home builder must feel compelled to partake as they know that not participating will be a competitive disadvantage. The first step of reviewing possible solutions is to understand the functions to the business approach. A function diagram will give us the key points to define in order to determine how the product requirements will be met. A basic example is given below in Figure 12.

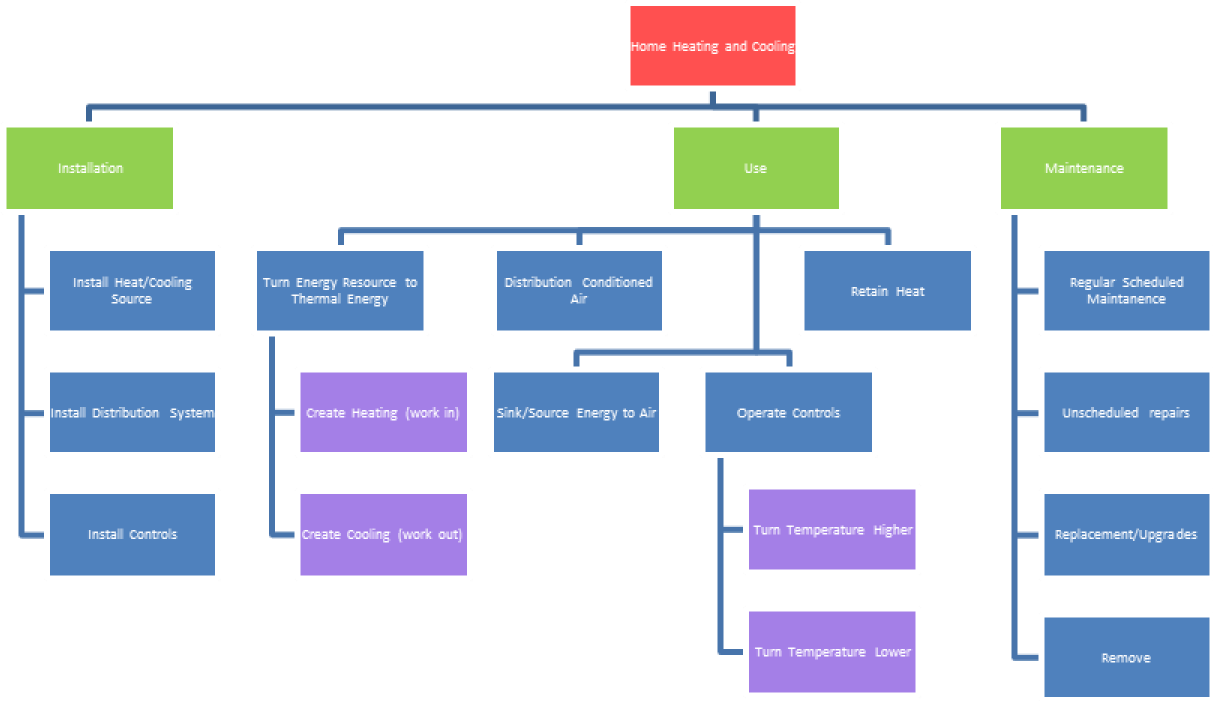


Figure 12: Function Decomposition Diagram for Home Heating and Cooling

9.1 Functional Decomposition Concept Generation

The top level requirements—as previously stated—allow the home owner a neutral cost alternative that is reliable. The baseline system is easily accessible because the home builder is motivated to provide the option in order to stay competitive. By comparing the functional parts of providing heating and cooling to these requirements, we can begin to generate new concepts that relate tangible actions to tangible results. An instance of this is comparing function of installation to the requirement of cost neutrality. An outcome of this might be to review options that remove the home owner from capital ownership of the system. This could be achieved by having a third party owner who is willing to pay for the capital up front in exchange for a profit margin in use cost.

9.2 Integrative Design and Factor 10X Concept Generation

The key principles of integrative design and factor 10X design applied to home heating suggest to start with no preconceived notions of home heating, look to simplify complicated practices and to incorporate as much multi use functionality as possible. The strategy of heating homes has not changed much since ancient history. The majority of homes around the world still rely on a single source of heat that was built only for their home. This concept misses out on the idea that in a fully realized market, the final result should be home heating *for* every home and not necessarily home heating *in* every home. In reality, a way to lower the cost of alternative systems is to review the strategy at a larger spectrum than just a single home. One possible outcome of this would be to review community systems in place of the traditional system. In most economies of scale, the upfront capital cost of installation is not scalar to the end product and is oftentimes more economically efficient at larger capacities. Other options looking at the functional decomposition matrix suggest that integrating "use" function could have beneficial gains. One example might be to review concepts that integrate other houses functions with home heating. Examples of these could include hot and cold water with solar heating as well as geothermal.

9.3 Double Reverse – Optimal Design Criterion Selection

A common method for concept generation is the Double Reverse. This method is taught in many Design For Six Sigma (DFSS) courses. The purpose of this generation technique is to identify key attributes of the desired design based on upon what negative outcomes are most apparent. For this reason it is called the double reverse in that negative attributes are generated firstly, and then the reversed optimal outcome is seen generated. Looking at the outcome of optimal attributes, the optimal design will introduce no more complexity to the home owner. As well the system will not introduce any complexity to the reimbursement or initial cost to make it cost neutral. The ideal design will also rely on a resource that is readily available with little to no infrastructure needs to implement. The results can be found in 0**.**

9.4 Concept Generation by Category

Another method to generate concepts is by identifying the key entities that facilitate the functions described in the function decomposition matrix. These key entities are technology, implementation and cost. The resultant combinations result in 3 possible technologies (as an alternative to conventional systems), 6 possible construction strategies, and 3 proposed payment schemes. This results in numerous strategies of high level concept design. This is the boundary of options that will be entertained for this project.

9.4.1 Proposed Technology Generated Concepts:

Electric Generated Heat and Cooling/Ductless Electric

<u>Scope:</u> This is a current application that is not as widespread as natural gas conventional furnaces. This relies on resistive elements to create the heat source and a traditional compressed refrigerant for home cooling. This can use traditional ducting systems or displaced systems in every room.

<u>Advantage:</u> The primary advantage to this technology is that it displaces the requirement for fossil fuel generated heat.

<u>Disadvantages:</u> This does not provide a complete solution as a majority of electricity is still generated from fossil fuels. This system overall can be more costly than conventional systems. This solution also does not provide a new resource to capture energy from in place of current energy markets.

Solar Thermal Heat/Passive and Active Heating

<u>Scope:</u> Active or passive heating using solar collectors and selective design of the home to optimize energy retention in cold climate and dissipation in hot climate.

<u>Advantage:</u> The advantage to this technology is that it utilizes an overall more efficient use of total energy to accomplish the task at hand. It also does this with a currently underutilized resource (solar).

<u>Disadvantages:</u> This solution requires strategy home design as well as a back-up system. Depending upon the reliability of the system this may increase the overall cost dramatically as the system becomes completely redundant. There is a limitation to the available footprint for a system such as this as it

requires visible sunlight that is unobstructed as well as a reservoir of water/liquid to retain the heat at times of no sun.

Ground Source/Sink Heat Pump Systems (Geothermal Heating and Cooling)

Scope: The strategy of this technology is to source/sink thermal energy from/to the sub terrain via a series of wells that are interconnected. This resource provides a resource to heat/cool air to a nominal value year round. A secondary electric system that is sized much smaller provides the additional support to raise or lower the temperature further from the nominal.

Advantage: The advantage to this technology is that it is a more efficient use of total energy to accomplish the task at hand. It also does this with a currently underutilized resource (geothermal heat).

Disadvantages: This solution requires strategy home design as well as a back-up system. Depending upon the reliability of the system this may increase the overall cost dramatically as the system becomes completely redundant. The footprint of this system is limited as well, but not as much as solar due to the fact that most of the space required for it can be reclaimed as the system is underground.

9.4.2 Construction and Implementation Generated Concepts:

New Housing or Retrofitting Homes

Scope: Finding the future's home heating and cooling energy needs will mean looking at current inventory of homes as well as new housing. This could mean targeting new housing only or also pre-existing homes.

Advantages: The primary advantage to looking at retrofitting homes as well as new construction is a much larger target of available homes to work on.

Disadvantages: Current data gathered suggests that most home owners are not active stakeholders in their system, so the likelihood of transforming homes with pre-existing systems seems limited at first review.

New Housing Standardized Design or Custom

Scope: Will the new housing be restricted to a specific design or will the implementation allow "one size fits all"

Advantages: Standardized housing allows a larger target penetration for homes. Customized homes may have more advantageous capital expenses.

Disadvantages: Customized homes may target a higher cost home market which is smaller than those who build standard homes. Standard homes may have inefficiencies for interfacing the new technology. This could cause operational or financial issues.

Single Housing or Community Systems

Scope: Construction of the chosen technology may be reviewed as a single family home or as a communally shared venture.

Advantages: Economies of scale for larger systems that could be communally shared could have economic benefits. Single homes may offer more continuity to the homeowner.

Disadvantages: Communal operations will typically target a shared ownership or third party system. Single family homes may increase the burden of installation.

9.4.3 Payment Generated Concepts:

Private Ownership

Scope: The homeowner will be the primary owner of the system. Tax incentives would be covered under this category as well since the homeowner must fund the project before reimbursement.

Advantages: The homeowner maintains full power over system

Disadvantages: The homeowner is financially committed to the installation, operation and maintenance of the technology.

Robin Hood Ownership

Scope: A regulated tax is charged on conventional fuel systems. This tax is used to fund a capital cost refund grant for new systems.

Advantages: The homeowner is financially free of upfront capital costs (for duration of fund).

Disadvantages: This creates a higher burden for those unable to switch from conventional. This system is also only sustainable until the amount of capital from conventional use runs out.

Third Party Ownership/Utility

Scope: All system capital costs are covered by a third party entity such as city, HOA or regulated utility. Cost for system and maintenance is collected by an operation fee (metering system)

Advantages: The homeowner is financially free of upfront capital costs (for duration of fund).

Disadvantages: This requires ownership burden to an entity that does not currently exist.

9.5 Concept Results

The results of the numerous generated concepts have been included in 0. Of the ideas generated, several have been reviewed in greater detail to demonstrate the key options and alternatives found. These can be seen described below.

9.5.1 Community Geothermal Utilities

The scope of the community utility design concept is to emulate the application of Ball State University's centralized hot/cold water system on a residential application. The concept would integrate the heating and cooling system into a residential utility that every house uses. The capital expenditure would be incurred by a third party investor which could be private or regulated. Since the system would be large and inclusive of every home, there would be no need for isolated system design; rather every house would run in parallel to a main system that was pumped by a central pumping station.

The main benefits of a system such as this are the end user is removed from the capital expenditures and maintenance of the system. The home builder is still installing an in-home system—at a fraction of the cost—and is now only required to install a simple air handling unit versus the entire pumping and monitoring system. The aspect of this that is still not determined is the motivation for the home builder to participate. This could be something resolved by means of municipal zoning requirements or legislative action. Such a motivator could be a challenge to implement as most municipalities are not fiscally viable to support such an endeavor. Further development would likely require a business plan that could be used to sell the idea to traditional loaning institutions.

9.5.2 Ductless Electric Homes Incentive

Reviewing the functional design and factor 10X designs, it might seem logical to review the need for ducting systems at all. With the ductless electric systems, this removes the need at beginning of construction to install any system at all. With this system, no fuels are required and there is the possibility of the generated electricity to be completely clean. Most importantly, this proposal would not require a large investment by the government stakeholder as only a regulation to implement would be required.

The main issues with this design are that it does not provide a complete solution as a majority of electricity is still generated from fossil fuels. This system overall can be more costly than conventional systems as it typically will require the same size system in every room regardless of actual need. As well, this solution also does not provide a new resource to capture energy from in place of current energy markets.

9.5.3 Robin Hood Incentives and Taxing for Carbon Neutral Heated Homes

The primary hurdle that each concept struggles with is the motivation for the home builder. Current legislation incentives have only assisted a marginal share of the market in spite of the long term gains for those who participate. From the data gathered, these incentives have not helped persuade home builders to encourage customer participation. As shown in previous sections, the ability to capture new markets with capital investments that have a payback longer than five years is nearly impossible. Looking at the possible outcomes, one approach might be to reconsider changing the entire market with a capital grant fund that funds 100% of the expense from a fossil-fuel tax.

The primary advantage of this approach is that it could be implemented and adjusted very easily. The customer concerns with capital expense would be removed because all payments would be made indirectly from the tax fund. As the initial implementation begins, the population of taxed homes paying into the fund will be very large. As this fund pays the capital expense of new systems it will shrink in balance of the growing alternative market. In the end, the tax rate and geothermal penetration rate will be adjusted to work in harmony creating a cash flow for capital expense that pays for future systems. The primary disadvantage of this system is that it taxes all houses on a flat use rate, essentially disparaging the poor to improve the wellbeing of those who can afford new homes or retrofits. As well, this plan requires legislative action that may be unachievable.

9.5.4 Sub Terra Housing Initiative

Reviewing the factor 10X design principles, one of the key factors that become apparent for modern housing is insulation of the home. With as much energy spent heating homes, very little is spent on retaining the heat more effectively. If homes were to be built below ground level, much of the heat transfer that occurs would stop dramatically and instead be replaced by only the conduction of heat to or from the earth. With this change, the size of the system would likely shrink dramatically.

The major benefits of a concept such as this are that it requires little to no technological improvement to implement. Nearly all homes in Michigan are built with basements and this would simply be an extension of that idea. As well, because the idea is simply reducing the overall need for energy to heat or cool the home, the replacement of the technology would not be necessary; instead the homeowner would be allowed to entertain any concept for home heating and cooling. The major drawbacks to this proposal are that the majority of the stake holders will have to commit to entirely new environments. While most homes do have basements, it is not common to have no existing house above the terrain. This would be new territory for both the builder and buyer. Such a change could bring negative aspects such as unwillingness to reside or participate. This is something city planners would be sensitive to and would likely not be willing to support.

10 Concept Selection

In order to come up with the best overall concept, we needed to rate our overall concepts, technology concepts, construction concepts, and payment concepts. We constructed multiple Pugh charts in order to rank the concepts against each other in terms of our selection criteria. The selection criteria was developed from our functional decomposition and weighed with the aid of our quality function development (QFD) results. Both of these tools showed us that cost was the most important factor, so it is the highest weighted criteria. The Pugh charts list the selection criteria in the leftmost column and their weights in the adjacent column. The values for the weights of the selection criteria are one through five, five being the most important and one being the least important to our stakeholders. The weights of the criteria were determined based on our ethnography and other research as well as the results of the QFD. For each concept, a score was assigned based on how well they met the selection criteria. The scoring system was simple: either it positively met the criteria (+), was neutral towards the criteria (0), or did not meet the criteria (-). These ratings were assigned and multiplied by the weights to get a total count of the positive, neutral, or negative response to the selection criteria. All scoring was completed in the mindset of the key stakeholders, the homebuilders and the homebuyers. If something did not apply to the homebuilder, then the homebuyer's opinion was used and vice versa. The selection criteria chosen as well as the weights of each one can be seen in Table 2.

Selection Criteria	Weight
Cost Effectiveness	5
Monthly Cost Savings	5
Available for new construction	4
Reliable	4
Long Lifetime	3
Year Round Comfort	3
Reduction in Materials	4

Table 2: Selection Criteria used for Pugh Charts

The results from the evaluation of technology concepts and construction concepts would be used to reaffirm the results of the overall concept Pugh chart. As can be seen in Table 3, community geothermal comes out as our top concept when rated against the selection criteria. Table 7 and Table 8 in Appendix 6 reaffirm this decision as geothermal came out on top in the technology evaluation and new housing, community, and standard build came out on top in the construction evaluation. Third party ownership came out on top as far as payment options are concerned. The relationship of the payment concept with the design chosen will be described later.

Overall Concepts		Concept 1	Concept 2	Concept 3	Concept 4
		Community Geothermal	Ductless Electric	Robin Hood Incentives/Taxing for Carbon Neutral Homes	Sub Terra Housing
Criteria	Weight				
Cost Effectiveness	5	+	0	+	0
Monthly Cost Savings	5	+	0	0	+
Available for new construction	4	+	+	+	+
Reliable	4	+	+	0	0
Long Lifetime	3	+	0	0	+
Year Round Comfort	3	+	0	0	0
Reduction in Materials	4	+	0	0	+
+		28	8	9	16
0		0	20	19	12
-		0	0	0	0
Net Score		**28**	**8**	**9**	**16**

Table 3: Overall Concept Pugh Chart

11 The Alpha Design

The design that will be explored further for our alpha design is a community geothermal system. Like a traditional geothermal design, this design uses the Earth as a heat source/sink depending on the season. The major difference is that instead of servicing a single home, this system would service multiple homes in a community. Instead of each home having its own heat pump and geothermal loop system, there is a central pumping station that contains the loop system and heat pump for the whole community. The pumping station will have a much larger loop system and much larger heat pump than any individual homes would, but the thought is that the overall cost of the single system would be less than all of the individual systems combined. The motivation for this type of system came from the campus wide geothermal system that Ball State University is in the process of installing on their campus (Ball State University 2013). There are three portions of this system that require explanation: the well field, the pumping station, and the in home portion.

Before diving into the specifics of each of these portions, it is helpful to first explain the overall layout of the community. The layout of the community is shown in Figure 13. The overhead view looks like any other subdivision, but there are two water loops that extend throughout the community. One loop is a hot water loop and the other is a cold water loop. The hot and cold water are generated from a heat pump located in the pumping station. Depending on the temperature set point desired, each home will take in either cold or hot water and exchange heat with air to condition the home. After being used to condition the home, the spent water would be returned to the well field for reconditioning. This system allows for year round comfort of each home without requiring a backup electric system in each home as is required in standard geothermal systems since the hot and cold water loops will be at temperatures that are suitable for heating and cooling. Conventional geothermal systems require a backup electric system because the temperature below the ground may not be warm enough to heat the home in the winter or cold enough to cool the home in the summer.

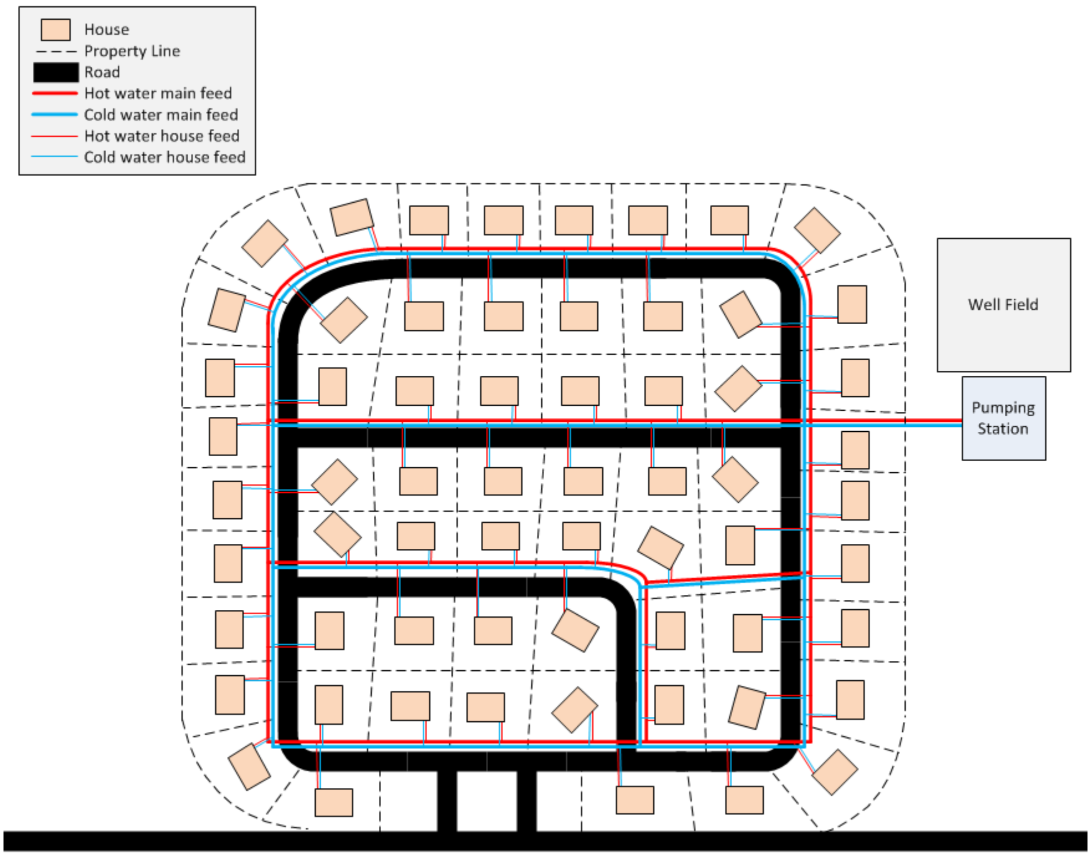


Figure 13: Overhead layout view of community geothermal system

11.1 Well Field

The well field is an essential part of the system and is the source of free energy that is used to condition the spent water to a consistent temperature for use in the pumping station. The number of wells will be dependent on the size of the community and the size of the houses in the community. Depending on the amount of land available for the well field, either horizontal or vertical loops could be used. Being that it is a high capacity system, vertical loops would be the better choice since they take up much less space. Each loop would be drilled approximately 400 feet deep to maximize effectiveness (US DOE 2012).

Since the wells are completely underground, the space above the well field could be developed into a community park or used in another manner to benefit the community. Figure 14 shows how the well field ties into the system; it takes in the spent water from homes and outputs constant temperature water for use in the pumping station. Since our sustainability analysis indicated that using PVC pipes are not a good choice, another material would be chosen that has a less harmful environmental impact but is still cost effective such as high density polyethylene or ABS plastic pipes (Natural Home Staff 2004). As will be made more apparent in the following section, while the pipes used must have a low environmental impact, they must also be well insulated. As described in the following section, they will be transporting water that is at an elevated temperature relative to the ground thus they require very low heat loss. Attention must also be paid to the longevity of the pipes used. Since the piping of this system must last for the life of the home, it is not acceptable to choose a piping material that is prone to break down over time.

11.2 Pumping Station

The pumping station is a generalized name for the structure in which the output water of the well field is turned into hot and cold loops and is pressurized for distribution throughout the system. The hot and cold water loops are created using a heat pump or a series of heat pumps depending on system size. The heat pump consists of four basic components; a compressor, condenser, evaporator and expansion valve. An environmentally friendly working fluid, such as R-134A or R-410A would likely be pumped through the heat pump. It should be reinforced that there is no mixing of the water from the well field and the refrigerant as both are closed systems. The well field water is also not mixed with the drinking water supply as its sole purpose is for heating and cooling purposes and not drinking. Depending on the location of installation, the well field might require a refrigerant instead of water to avoid freezing. The refrigerant in the heat pump first enters the compressor, which works to increase its pressure and temperature. Some of the water from the well field is transferred across the condenser (essentially a heat exchanger) and exchanges heat with the refrigerant. The condenser heats up the water while cooling the refrigerant and thus creates the hot water loop. The refrigerant then flows through the expansion valve, which decreases its pressure and temperature. The rest of the water from the well field is transferred across the evaporator (which is also a heat exchanger) and loses heat to the refrigerant. This creates the cold water loop. The refrigerant is then returned to the compressor. Since the inlet water from the well field will be the same temperature year-round, both the hot and cold water loops will also be the same temperature year-round. For reference, the Ball State system produces a cold water loop that is a constant 42°F and a hot water loop that is a constant 150°F (Ball State University 2013). This system would be expected to provide similar temperatures for its hot and cold water loops. It is for this reason that the pipes must be well insulated.

The pump shown in Figure 14 is necessary to circulate the water in the hot and cold loops to the homes in the community. Since the homes do not pump their own water through the loop system, this pump is necessary to pressurize the system and enable water flow through the houses.

The energy input into the system, specifically into the compressor and pump, is purely electrical. Depending on where the system is installed, this electricity could be generated in an environmentally friendly way resulting in near zero greenhouse gas emissions for the community.

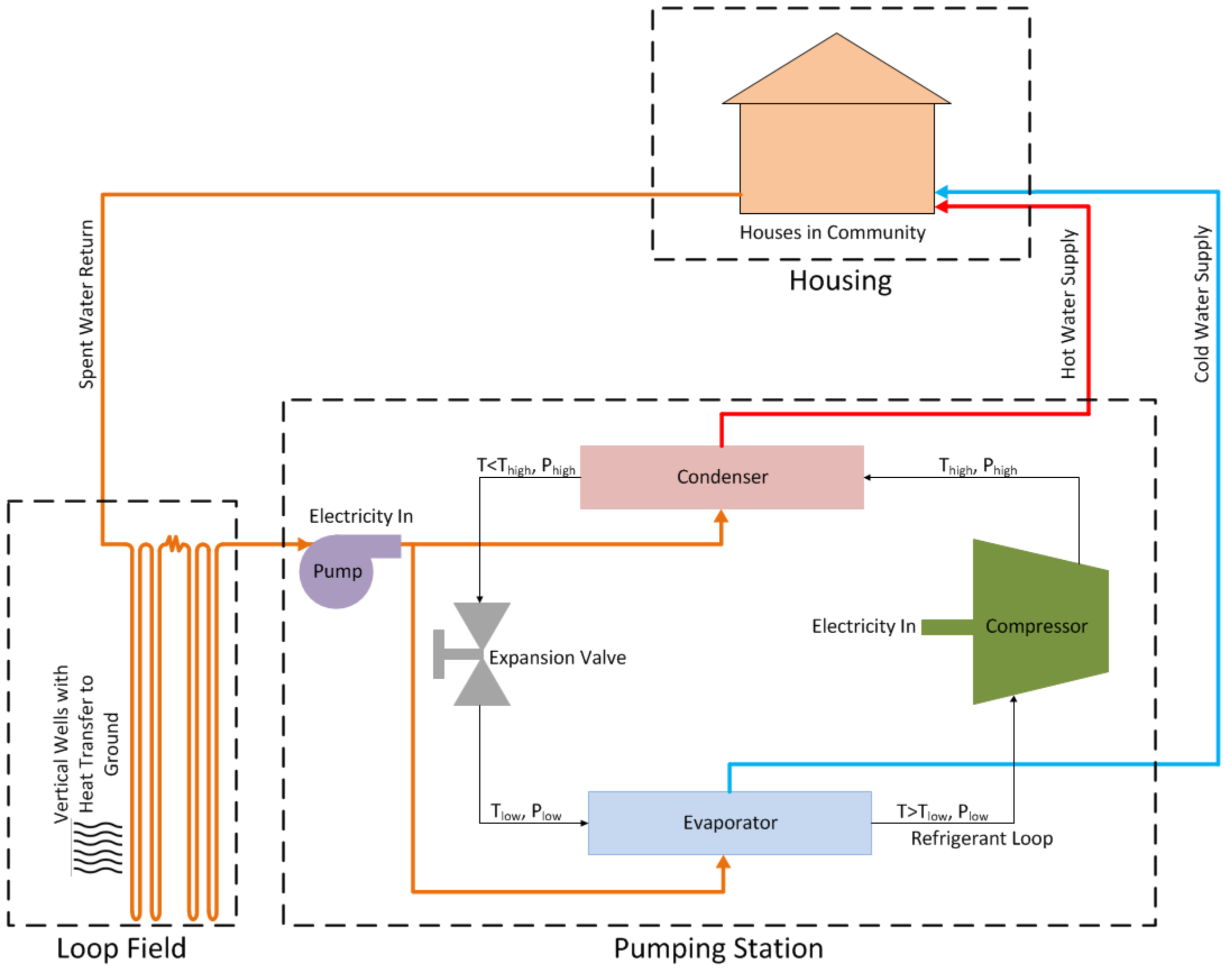


Figure 14: System layout of community geothermal system

11.3 In-home portion

As can be seen in both Figure 14 and Figure 15, the input into the home is the hot and cold water loop and the output from the home is the spent water. The components of the indoor system are highly simplified over both a conventional forced air and a standard geothermal system. First of all, there is no outdoor component to be installed at each home site as there would be in a conventional forced air system. As each additional home is built, it just needs to tap into both the hot and cold water loops as well as the spent water loop. The indoor component consists of an air handling unit and a simplified hot water tank. The air handling unit has only three components – a heat exchanger, circulation fan and a solenoid valve module. Depending on whether heating or cooling is desired, the solenoid valve module will allow water from the hot or cold loop to enter the heat exchanger. The circulation fan will blow air from the return ducting across the heat exchanger which will in turn either heat up or cool down the air. The conditioned air will be circulated throughout the home via the circulation fan. The home will be equipped with standard ductwork to distribute the conditioned air throughout the home. This air handling unit is much simpler than a conventional geothermal heat pump or a gas furnace. It does not contain the burner that a gas furnace would contain. It also does not contain the heat pump or back up electrical system that a standard geothermal unit would. The lack of an electrical backup would save money in upfront costs as well as monthly electrical costs. It is not needed due to the sufficiently high and low temperatures of the water being circulated through the system.

The simplicity of this unit will lead to a much lower cost and improved reliability over other systems as well as a reduction in materials over a conventional forced air system. While difficult to estimate, the cost of this air handling unit may be approximately 30% less than a furnace due to the lack of the burner, gas handling, and exhaust fans. Again, this is a ballpark figure and is only based on prior knowledge since no data could be found on the breakdown of the cost of a furnace. Based on the cost data presented in section 3.2, this would put the cost of this air handling unit at $5,600. Since no air conditioner is required, the total cost of the indoor system to the homeowner would be only $5,600 instead of $13,000. With the application of the 30% government rebate available until 2016, the cost of the indoor portion of this system would be less than $4,000 for an average home.

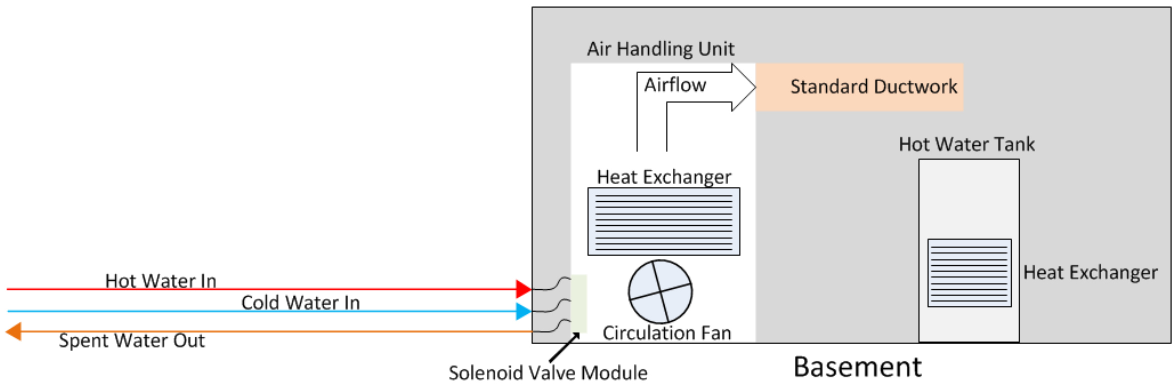


Figure 15: Home indoor portion of system

The hot water loop is also connected to a simplified hot water tank. There is no boiler needed for this tank, only a heat exchanger. The water from the hot water loop would flow through the heat exchanger and heat the water inside. The hot water loop and the useable hot water in the tank would not mix together. The lack of a boiler would reduce cost and likely increase the useable life of the tank.

Due to its overall simplicity, the lifetime of the indoor system will easily be able to meet the goal of 20 years or more. It will also be more reliable than a conventional system due to parts reduction and provide the same level of comfort or higher since the outdoor air is not pulled into the home thus affecting the humidity levels.

11.4 Alpha Design Summary

Overall, the in-home portion of this system is more cost effective and more reliable than other systems. It eliminates the need for the outdoor air conditioning unit of a forced air system and eliminates the need for a backup electrical system in a conventional geothermal system. There are far fewer serviceable parts as well which would ensure that the lifetime of the in-home portion exceeds 20 years. Since it is far less expensive than a conventional system, the payback period is non-existent. The comfort level in the home would be the same or higher than the baseline system and the risk of carbon monoxide poisoning and fire is eliminated. The monthly electricity usage of this system would be less than a conventional geothermal heating system (due to lack of electrical backup) and forced air system (due to lack of outdoor air conditioning unit). Electrical usage would also be fairly similar across seasons because there is no extra component that consumes more energy seasonally. The community portion of this design is more complicated than a standard geothermal system, but if properly sized and designed should allow for an overall reduction in energy usage across the whole community. The community portion of this system (pumping station and well field) will also be reliable and while the heat pump will likely not last 100 years, the well field should not need to be replaced.

The elephant in the room is how to pay for the community portion of the system. It is likely that the homeowner would be responsible for funding the portion that resides in their home, but due to the simplicity of this system, their upfront cost would be much less than a conventional system due to the lack of an air conditioner and simplification of the air handling unit over a furnace. If a third party such as a municipality or a utility were to pick up the cost of the community portion, then they could charge a usage fee to the homeowners. The hot and cold water lines would have meters in each home and the utility would charge the homeowners for their usage of the system. The homeowner is paying much less upfront for the system and is paying less for electricity than a standard geothermal system and much less than for a conventional forced air system. This frees up some budget to pay the system owner a usage fee for the hot and cold water. The detailed business plan and method of funding the community portion of the system will be described in further detail in the final report.

12 Alpha Design Improvements over Baseline

A neighborhood built with our community geothermal system would exude many advantages over a neighborhood built with individual forced air systems with gas burning furnaces and electric air conditioning units. The major categories that show these advantages are cost to the homeowner, reliability, materials usage, and emissions.

12.1 Cost to the Homeowner

As discussed in section 11.3, the upfront cost to the homeowner would be much less than a conventional system and far less than a standard geothermal system. This of course is heavily dependent on where the funding for the outdoor portion of the system comes from. Assuming that a utility or municipality pays for it and charges the homeowners a usage fee, the only upfront costs for the homeowners to pay is the cost of the air handling unit and simplified water tank. The air handling unit would cost somewhere around $5,600 or less, which is a significant savings over purchasing either a gas burning furnace plus electric air conditioner ($13,000) or purchasing a standard single home geothermal system ($26,000 or $18,200 with rebate). Assuming that the 30% government tax incentive would apply to the air handling unit, its cost would be less than $4,000. Usage fees would vary based on the electricity rate to power the pumping station. Based on real data from a house with a standard geothermal system, we estimated that the electric usage for conditioning a home in a geothermal community to be approximately 350 kWh per month (see Appendix 7 for this calculation). At a national average residential cost of $0.121/kWh (US EIA 2013), this works out to about $40 per month during either winter or summer. The average home in the US consumes approximately 500 kWh per month for heating and cooling (US EIA 2013), but this does not include natural gas or other fuels. Most homes have a gas bill for space and water heating in addition to their electric usage, which would be eliminated by a community geothermal system.

12.2 Reliability

In general, the fewer parts you have the fewer problems you have. This would be the case for the in home portion of the community geothermal system. From personal experiences, the most common issues with conventional systems have to do with the burner inside of the furnace. There is no need for a burner in our alpha design. The sheer simplicity of the system compared to our baseline system will make for a much more reliable design.

The pumping station is the other area where reliability would be a concern. If the heat pump fails, then the whole neighborhood is without heat. However if the system were owned by a utility, then it would be properly maintained and repaired promptly. This would be analogous to losing power (which prevents furnaces from operating) and waiting for the electric company to turn it back on. The system should be very reliable and should only stop working when power is lost, as would baseline systems.

12.3 Materials Usage

The individual home portion of this system achieves a significant reduction in materials compared to a conventional forced air system. The air conditioning unit is completely eliminated as is the components of the furnace that are specific to the combustion of the gas. A conventional forced air system does not contain any materials outside of the home besides a gas line and the electric lines. The community geothermal system however relies on a significant amount of piping outside of the home as well as the heat pump. A lifecycle analysis would need to be performed to ensure that the removal of all air conditioning units and combustion components in all the homes in the community make up for the additional piping and heat pump required by the community system.

12.4 Emissions

The community geothermal system has a trade off in emissions in its use phase versus a conventional forced air system. For each home, the emissions should be reduced significantly. In section 8.5, it was shown that an individual geothermal home had greater than a 50% reduction in utility costs and emissions compared to a home using a propane forced air system and electric air conditioning. The pumping of a larger system will be more efficient and should reduce costs and decrease carbon emissions even further. Depending on the location of the system, the electricity may be generated in an environmentally friendly manner which would further reduce carbon emissions. Using the estimated electricity usage in a single home in the community system of 350 kWh/month, each home would produce only 5,485 pounds of CO_2 per year (US EPA 2012) which is far less than a forced air system (~20,000 pounds of CO_2) and also less than a standard geothermal system (~10,000 pounds of CO_2 per year or less).

The water loop is a closed system, so drinkable water is not being used and disposed of rather the system is self-contained and does not require fresh water to operate nor does it contaminate groundwater. The only input into the system once operational is electricity.

13 Feedback on Alpha Design

In order to validate our concept, it was necessary to seek out feedback from stakeholders. Feedback was received from two sources: Randy Byrne, a former city manager who now works for the state on financially distressed communities, and Greg Henderson, a builder. The notes from the discussions with them can be found in Appendix 4. Neither one had personally seen a combined heating system used for a subdivision. However, both found the concept interesting. Mr. Byrne indicated he was sure that these projects like this exist and they had been funded through federal and state funding.

Mr. Byrne provided additional insight into decision making at a municipality. Possible champions at a local municipality were expanded to include the city manager, city council personnel, knowledgeable persons of grants and opportunities, department heads or knowledgeable citizens. Feedback was also provided about what is needed for a successful municipal project. In order for a project to get approved at the municipal level, it should have two characteristics: they fulfill a need (e.g. outdated systems, expensive repairs, inefficient) and they are funded by grants or low cost loans.

For energy related projects, this funding tends to come from the State of Michigan Energy Department. Follow-up research was done to get a description of projects that the Energy Department has funded. One such project is the Kent County Correctional Facility. Through a $1M grant from the Energy Department‘s Energy Efficiency and Conservation Block Grant (EECBG) Program, this facility converted to geothermal energy (US DOE 2013). Funding is also potentially available at the federal level. Information on federal grants is available at the Department of Energy's website (US DOE 2013). Additionally non-profit foundations such as the Mott Foundation have been known to provide funding for community projects (Mott Foundation 2013).

Insight was also provided regarding how to market such a project. The Michigan Municipal League is an example of a method of distributing information about projects like this. Such organizations are non-profit foundations dedicated to supporting local government leadership and development (MML 2013). The marketing plan was updated to involve these two new resources to investigate grants available at a state and federal level, and to provide information to municipalities via workshops and conferences run by government or liaisons. The marketing plan was updated to include communication with municipalities through workshops and conferences run by government or liaisons and to investigate grants available at a state and federal level.

Mr. Henderson provided information on the relationship between the builder and the municipality. There are significant funds that are paid by the buyer to the municipality for utilities and the builder has to have approved permits. This gives the municipality influence over the builder through zoning and reduced feeds for utility hookups. A builder of a subdivision can move very quickly to make 100 to 300 houses go up in a few months, so delays are to be avoided. Most subcontractors are locally supplied. The builder tends to be very conscious of cash flow. This made us realize that the implementation of the community portion of the design has to be done in a timely fashion.

14 Final Concept Description

Based on the feedback obtained, the following items were changed for the final design:

- the persona description was broadened to include a variety of roles at the municipality (as described in section 13)
- the financing strategy was updated so that it creates a revenue stream for the municipality and provides a way to fund the project
- the business plan was updated to include the need for grant research at the federal and state level
- the marketing plan was changed to include information distribution through government workshops and conferences as well as through liaisons like the Michigan Municipal League

The final design is going to target municipal run community geothermal system whose capital cost is funded with the aid of government or state grants. The alpha design considered the system being funded and owned by a municipality or utility, but our feedback has shown us that municipal funding is not likely to lead to implementation of this project. Federal or state grants are necessary to implement a community geothermal system as the cost to the utility is not justified by the need for a source of revenue without them. The marketing strategy will utilize resources such as the Michigan Municipal League to form contacts with the key positions noted within municipalities. The physical layout of the design has not changed and can be viewed in the alpha design section. Geothermal has been implemented for decades in residential housing and municipal buildings, so the technology is low risk. At this point in the design process, not enough details are known to make changes to the layout of the design.

15 Business Plan

In order to take our community geothermal design from concept to reality, a business plan must be developed that includes a description of our potential business, an analysis of the current market for our product, a description of our product, a marketing strategy, and necessary funding to start and sustain the business. Without a business plan, our concept is just that – a concept.

15.1 Company Description

Our proposal for a company is for a design firm of community geothermal systems. The need addressed by our company would be to provide municipalities with a source of revenue through the metering of community geothermal systems while utilizing a sustainable resource for home heating and cooling. The company would design, build, and sell the systems to municipalities as well as work with them to win federal or state grants to offset or pay for the capital cost of the community portion of the system. To keep labor costs low, the company would contract out its designers as well as builders. The focus of this business plan will be on our primary target for this system which is new housing developments, but as our company matured we would consider other avenues for community geothermal including new commercial developments as well as retrofitting existing commercial communities with community geothermal systems. We would market to municipalities and utilities interested in creating an additional stream of revenue from community geothermal usage fees that is also environmentally sustainable and may be eligible for grants, tax breaks, or special financing. Our company would also work extensively with builders of new housing developments to integrate our system to work with their plans. Additional stakeholders would be federal and state governments who may provide the grants, tax credits, and or special financing as needed. Community geothermal addresses several problems including: fluctuating fuel costs, fluctuating seasonal heating and cooling costs, greenhouse gas production, and the lack of natural gas infrastructure in certain areas. Geothermal amends these problems by eliminating the need for natural gas or other fossil fuels, reducing electrical usage and reducing seasonal energy usage variation. Additionally there is a potential that the electricity can come from a clean source which would further reduce overall greenhouse gas emissions. The in home portion of this system is also much less expensive than a conventional forced air furnace with electric air conditioning, so there is less of a burden on the homeowner as they own less of the system than they otherwise would. The community geothermal system can provide a positive cash flow without special financing, so unlike most new technologies, it is cost competitive with its non-sustainable alternative.

15.2 Market Analysis

Our target market is the new housing market. Sales of new single-family homes in October 2013 were at a seasonally adjusted annual rate of 444,000, which is above the October 2012 estimate. The average sales price was $321,700 (U.S. Department of Housing and Urban Development 2013). This shows that there are a lot of new houses being built across the country. A figure of which percentage of these are built into subdivisions was not available, however one can assume that there is a large number of new housing developments that would make excellent candidates for a community geothermal system. The key is to target the local municipality well in advance of the construction of new houses in order to ensure that sufficient planning and zoning can be done.

The real estate industry experienced tough times during the last recession when foreclosures rose and current housing prices fell dramatically. The result was a significant number of current housing units on the market at low prices, and a reduction of new units requested to be built. The overall housing market is recovering, but is still in the initial stages of that recovery. Starting our company when the housing market is still in the recovery stage may prove to be excellent timing as new opportunities for installation will grow as the market continues to recover.

The main competition for our company is the case of business as usual. The fact is that most homes are built with conventional forced air systems and homeowners are content with them. The most difficult challenge for our company to overcome is convincing the municipality that a community geothermal system will provide them with a revenue stream and not pose any disadvantages for the homeowner. Since this is a unique system, there may be zoning challenges that need to be overcome in certain cities. The advantages that our design poses over conventional forced air systems is that the in home portion is much less expensive, the homeowner's monthly heating and cooling bills will be stabilized throughout the year, and the municipality can collect usage fees similar to the fees it collects for water and sewer service.

15.3 Product Description

Geothermal has the potential to significantly lower energy needs for a single unit residential system, but it generally has a higher capital cost. For larger systems, geothermal offers an additional attraction as the on-going utility costs are still less than conventional systems, and the capital cost penalty can be greatly reduced. This is because much of the piping and pumping equipment needed for geothermal heating is centralized and distributed throughout a housing community rather than a single residence. Our company specializes in the design and construction of custom community level geothermal systems for residential communities. All of the homes in the community are tied into a system that utilizes the natural heat of the Earth to provide heating and cooling. The upfront costs to the homeowner, monthly heating/cooling costs, and carbon dioxide emissions can all be reduced by more than 50% compared to a conventional system. This is due to the simplification of the in home system and the elimination of fossil fuel usage and the electric air conditioner. Sales to home buyers are particularly attractive as the capital cost of the community portion of the system is transformed into a metered service. Currently, our company is looking for a municipal partner to build a prototype of our concept and demonstrate that it can operate reliably and provide a positive cash flow. In short, our systems can provide a lower cost system to the homeowner and a sustainable source of revenue to the local municipality. The city manager we interviewed indicated that the idea of community geothermal was not "far-fetched" and would be attractive to an environmentally conscious municipality. With the benefit of bringing in a revenue stream for the municipality and providing lower costs for the homeowner, we are confident that community geothermal systems will be well received.

15.4 Marketing and Sales Strategy

The difficulty with introducing any new product into the market, whether small or large, is reaching out to the customer and demonstrating that the product will meet their needs. A marketing plan has been developed that will help our company to reach out to the appropriate persons in municipalities and demonstrate that it will provide a benefit to their community.

15.4.1 Market Penetration Strategy

The key to our success is recurring growth in markets. In order to install the first system in a municipality, the company will have had to successfully market to the leadership, approved a strategy to implement the system and successfully carried out the installation. After this point, the ability to provide future services (if desired) will be much easier. For this reason, markets that have the highest potential for recurring business are the optimal target. With this growth strategy, a few initial systems in various markets could grow geometrically with each year. With the largest cost factor in operations being the staffing cost, the yearly overhead to operate is a nearly fixed cost. For this reason, the company must meet a minimal quota to break even of approximately $350,000. After sufficient initial markets are captured, the need to capture new markets would become less critical for solvency.

15.4.2 Communication Strategy

In order to get municipalities interested in installing our system in their community, it is very important that we form good relationships with them. This can be achieved through attending conferences and working within the Michigan Municipal League or equivalent in other states. We would also make up brochures or catalogs that we could hand out to various contacts we make to provide a visual representation of how our design operates and what benefits it could provide to both homeowners and municipalities.

15.4.3 Channels of Distribution Strategy

Our internal sales force will contact municipalities directly and will also contact manufactures of standard geothermal systems to leverage common suppliers of parts and possibly build the in home air handling units. Distributors would also be used for raw material procurement for construction of the community portion of the system.

15.4.4 Growth Strategy

To lower initial costs, all initial design and construction will be contracted out to existing firms. Eventually, it may prove beneficial to pull designers or construction workers in house. In addition to providing these systems for new housing developments, our business would consider expanding to new and even retrofit commercial community geothermal systems. This would open up our market and increase our revenue potential. We would also consider opening offices in other states in which the market allows for multiple projects to take place.

15.5 Necessary Funding

Our company is based upon a strategy to implement a sustainable enterprise for municipalities while creating a separate revenue stream that benefits from the developments of community systems. Under the best conditions, all capital expenditures would be provided through grants or other funding. Under the worst case, with prime interest rate loans, the systems for municipalities are capable of breaking even (or a debt-to-fiscal equity ratio of one) within 10.5 years per neighborhood system without any grant funding. The business that we intend to develop to foster these systems under the best case scenario could break even within four years—under expected growth—with a return on investment of eight percent in year ten. However, in the worst case scenario, the company would never generate enough revenue to break even. These scenarios are explained in more detail below.

The company will rely on an investor group to start. Initial funding will need to be approximately two million dollars to operate for five years. The needs of the company are primarily technical resources and staffing. A large portion of initial funds will be needed for payroll in the first few years until the initial design is released. After this, all future changes and contracting of design will be handled by a smaller support group of engineers who will manage the minor changes needed to optimize each system to its location. The company will rely on a small marketing budget as most marketing will occur on location or at conventions. Accounting, legal and other professional services will be contracted to minimize unneeded overhead. Our strategy is to design each system so that labor and installation will be contracted. This decision was made to pay more for initial builds by using third party installers so that the cost of overhead could be minimized when work is not occurring. As well, this allows the company to grow or shrink very quickly without delay or cost penalty. Appendix 8 shows greater detail with regards to net cash flow for the first five years for an optimally growing business.

The range of sales within the first three to five years could vary dramatically. Figure 16 shows that for a modest return, sales will have to exceed the anticipated $350,000 in yearly expenses and likely approach a million dollars. This would equate to an expected twenty systems or more. In order to remain solvent, the company would have to target at least a half dozen or more system installations yearly. An optimal growth strategy would be local governments slowly growing the size of their operations every year as well as new market penetration. A minimal growth strategy would likely resemble repeated case studies in new markets every year, but with no added growth in localities already targeted.

Figure 16: CGI Optimal Growth Trend

The municipal system is designed to operate by using existing resources for initial start-up and future growth opportunities if desired. Systems are designed for the capacity of a single neighborhood block. Due to lack of cost data available currently for a system such as this, it was estimated that the system would cost approximately the same as most commercial systems or approximately $2,500 per ton to install (William Goetzler 2009). Major infrastructure was estimated to require a twenty year life cycle with pumps and other wearable components having a maintenance cost anticipated every ten years. The system will be designed for autonomy with the exception of service, billing and administration. The cost of staffing overhead was amortized assuming that part time service would be available. This assumption was made as the job functions required are similar to other services provided and could be integrated initially. As well, the actual staffing requirements are minimal per each system. Capital cost for maintenance tools and resources were also included in the cost model. The cost model used in Appendix

9 assumed a cost to operate for home owners that would be comparable to propane or electrical furnaces. With the relatively low price of natural gas, it would likely require state or federal funding to offset the initial capital cost for it to offer a financially solvent operating cost.

16 Additional Reflections on Project Outcome

As the semester comes to an end, it is necessary to reflect on the progress that has been made and its strengths, weaknesses, what could have been done differently, and what is recommended should this project be continued in the future.

16.1 Sustainable Design Demonstration

The community geothermal system that we have developed is representative of sustainable design. It exhibits environmental, economic and social benefits. It reduces fossil fuel energy consumption at a cost competitive rate while transforming the way homes are heated and cooled.

The burning of fossil fuels in conventional heating and cooling systems is a major source of emissions for households. Using geothermal power as the major energy source eliminates the burning of fossil fuels and allows for an endless supply of energy to condition the water in the spent water loop to a constant temperature. The external power source for the system is purely electric, which allows for a variety of production methods to be used and can further shift away from the dependence on fossil fuels.

On top of using energy sources that are renewable or can be derived from renewable sources, the system uses less overall energy due to its optimization of resources. Instead of each home having its own heating and cooling system, each home has a very simplified air handling system and the heating and cooling ability comes from a combined system that extends throughout the community.

It has been shown that this system can be cost competitive with conventional forced air systems by reducing the capital costs to the user. It also can generate a revenue stream for the municipality to offset the capital cost that is not covered by federal or state funding or support normal operations.

Implementing a community geothermal system instead of conventional forced air systems utilizes the natural energy of the Earth rather than using fossil fuels. It provides a completely different way of heating and cooling homes that offers the same level of comfort for the homeowner as a conventional system.

A potential reason for the sustainability aspect of our design to not hold is if it is found to lack the capacity to effectively heat and cool the homes connected to it. Since the in home portion relies on the hot and cold water loop to heat and cool the home, other measures would need to be taken to condition the homes. Worst case, the community portion would be abandoned and individual homes would install conventional systems. This would cause the system to exude a negative impact on the environment since it did not function as intended. If not properly designed, unintended design issues such as leaks into the ground could produce negative lifecycle impacts. Future research might uncover that certain materials to be used might have more impact on the environment than originally thought.

16.2 Design Critique

The implementation of community geothermal systems was a strategy to renew the discussion about sustainable designs for heating and cooling of homes. The issue has been tackled numerous times focusing on the technology aspect of the solution without much consideration to what drives the change in the first place. The strategy of implementing a utility resource allowed a way to implement the system with limited participation by the users and a great deal of control by the key stakeholder: the municipal leader.

In future development more will need to be determined about the attitude of stakeholders to determine if the optimal persona was established. One key weak point was the amount of interviews conducted to establish a state-wide view with respect to homebuilders and municipal leaders. In the future, more home builders will need to be contacted in order to confirm the opinions and views gathered in the current research are true. As well, only one city planner was contacted to establish the persona as it stands. In reality, there may be better suited individuals in the local leadership. Ultimately, there may be another persona that is necessary to facilitate change; that would be an individual who can focus more state and federal funds to jumpstart these endeavors. In order to establish the validity of this hypothesis, more research would be required about the current and projected funding strategies of energy projects by the state and federal governments. As well, more would have to be understood about the roles of individuals who can implement change in these areas. Ultimately, they will be the key stakeholder for increased support.

16.3 Recommendations

If this project were to be further pursued in the future, there are a number of recommendations that we can suggest to get started. These recommendations can be separated into three categories: information gathering, design details, and alternative applications.

16.3.1 Information Gathering

The following are recommendations that we have for further research into the need for the system and inquiries to further pinpoint the persona.

- We would recommend to work towards strengthening the presumed need for alternative heating and cooling systems. It seemed clear to us at first that retrofit systems were not going to work since our research showed that people are content with what their homes are built with for the most part. The question arises whether the need for more efficient heating and cooling is a driver towards a change this drastic in the home heating/cooling infrastructure. It should be further explored what kinds of characteristics and price points for alternative systems will be acceptable to the homeowner, builder, municipality and utilities.
- We would also recommend making many more contacts with builders, municipalities, and utilities to better understand the extent to which each party is willing to go to install more efficient systems in their community. We did not have the chance to make a contact at a utility. Our research also showed that in order for municipalities to make large investments, they must be presented with a problem and funding. If the mass use of conventional heating and cooling systems is not a large problem, then a project like this might not even be on the table for a municipality. The limited time frame of the semester did not allow for a sufficient amount of time to establish and build multiple relationships with our intended persona. A more intimate relationship with a builder could have also helped us better understand underlying issues that could exist with the overall layout of our system such as what interferences may exist with other essential underground utilities.
- Another source of information to have a thorough understanding of is the fuel that is proposed to be replaced. Natural gas and propane in particular should be thoroughly researched and understood. The recovery process and availability of these fuels will play a large factor in the

success of a community geothermal system. This is similar to the issue with hybrid vehicles in which higher gas prices stimulate their sale and extremely low gas prices would hurt their sales.

- Research the different types of federal or state funding opportunities that exist that could be applicable to this product. It has become apparent that government funding will be necessary to get our product going, so research should be done to locate potential funding sources to target.

16.3.2 Design Details

- Instead of focusing on lowering the cost to the homeowner and pushing the large capital investment on another entity, it may be worthwhile to explore additional concepts that lower the capital expense of the community portion while keeping the cost to the homeowner at a similar level to the conventional system. While it is desirable for the homeowner to bear the least upfront cost possible, this makes for a more expensive community system. Alternatives should be investigated that allow for a lower cost community portion.
- Further consideration should be given to eliminating the heating and cooling components altogether (i.e. community passive solar). This is something that may not have as high of a capital cost to offset even if the upfront costs are higher.
- Variations for the community portion of the system should be explored. While the hot and cold water loops are a good concept, other options should be explored for delivering energy to each home for heating and cooling.
- Another area that could be explored further is a backup system. The current design will stop working either due to a loss of power or a damaged heat pump. A home with a conventional system and a generator can still heat their home in the event of a power outage. The current design would not allow for this since the pumping station would not be running without electricity. A battery backup or a generator system could be explored.
- In addition to a backup for the community system, it could be explored whether a backup system could be designed to feed both the community and individual home systems. In this case, in the event of a power outage, the community wouldn't be without heating and cooling.

16.3.3 Alternative Applications

- Rather than narrowing the focus to new housing developments, it might prove useful to further consider retrofit options. Creative financing options might make retrofitting make sense for a lot of different types of housing. These were ruled out by our team as our research showed that the homeowner did not exhibit a strong interest in changing the way they condition their home. Under certain circumstances and depending on how high their current costs are, retrofitting existing systems could prove to be a profitable business, especially if competitive financing strategies can be developed.
- There aren't any barriers to scaling the system to a larger level. Instead of homes, it could be applied to other types of developments such as business parks, industrial buildings, amusement parks, zoos, etc. Any centrally owned development with multiple structures could benefit from a combined heating and cooling system and our recommendation would be to explore this in greater detail and analyze whether it might make more sense in an industrial setting than a residential setting.

16.4 Reflection

After completing this course, the idea and process of sustainable design has become familiar to the members of this team. While the course content was very difficult to grasp at first since we're all engineers who are not involved in the customer needs part of the business, it became much clearer during the subsequent design reviews where we made more industry contacts and got more feedback on what we were doing and what the needs were. For future semesters, we would recommend more focus on the economic, environmental and social factors of sustainable design and less focus on life cycle analysis. While life cycle analyses are certainly important and should be a part of the content of this course, there was a lot of class time spent showcasing a practice that wasn't required for the term project. We think that a heavier emphasis on the economic, environmental and social factors of sustainable design would lead to a better final outcome for the term projects as these topics are very important practical aspects of sustainable design.

16.5 Acknowledgements

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Greg Henderson for his knowledge of the construction process and construction methodologies. He has helped us to understand that the builder and homeowner are not the target audience to reach out to to get the project funded.

Professor Steven Skerlos for his sound advice and constructive criticisms. He has helped us to dig deeper and really focus on the need for our concept as well as the persona we're targeting. We all have a much better understand of the thought and hard work that goes into designing a product that has a strong need and exhibits sustainable design principles.

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Appendix 1. Team Introduction

Doris Hill has been the Lead Test Engineer for Vibration, Safety and Abuse in the General Motors Battery Systems Lab in Warren, Michigan for the past two years. From 2009 to 2011, she was the Volt Program Manager for the Global Energy Storage Collaboration, a $61M collaborative project with the Department of Energy to develop the Chevrolet Volt and demonstrate it with 30 electric utilities in North America. From 1991 to 2009, she led GM's compliance to the European Union End of Life Vehicle directive, focusing on recyclability and elimination of hazardous substances. Eventually, she plans to retire to her geothermal home, garden, and watch the woodchucks and the deer as they drink from the geothermal fed pond. She likes the concept of sustainability as it means consideration of all stakeholders along with cost. Transferable skills include a personal knowledge of geothermal heating, excellent technical skills, and good writing ability.

James Knockeart graduated with a bachelors degree in Mechanical Engineering from The University of Michigan before hiring into General Motors as a hybrid battery test engineer. He has recently become a hybrid battery development engineer. He is pursuing a Masters in Energy Systems Engineering with anticipated graduation in December of 2014. Outside of work, he is intersted in cars, golfing, traveling and spending time with his wife. He is interested in sustainable design because it will become an integral part of the design process in the coming years. He is intrigued by simple sustainable solutions to large problems. He hopes to apply this thought process to the term project and develop an idea that is plausible for a more sustainable future.

Dan Witting is a Design Engineer for battery enclosures in the Global Battery Systems Group at General Motors. Dan's interest in sustainable design resides in the concept of better designed products for consumers. Product development that achieves sustainable implementation can be competitive in the mass markets of the global economy. Heating and Cooling of homes represents the largest consumer market for energy in the Midwest (for personal consumers) and he would like to take a chance at developing a smarter way of operating one of the primary objectives of houses. He brings a good share of creativity and abstract thought to the development of projects. He likes to make sure the information he is conveying is informative and entertaining to the reader in order to help bridge the gap between the informed and the uninformed.

Appendix 2. Environmental Impact Additional Information

Lifecycle Step	Description	Potential Environmental Impact
Materials	Plastic tubing for geothermal loop	• Excess material created during production may be discarded • Production techniques can produce toxic waste (CHEJ 2004) • Burning of excess materials can produce toxic gasses (CHEJ 2004)
	Working fluid for geothermal loop	• Certain refrigerants are toxic to produce (US EPA 2013)
	Metals or plastics for case of heat pump	• Wasteful production processes
	Metals, plastics, semiconductors for internal components of heat pump	• Wasteful production processes • Toxic byproducts of semiconductor production (US EPA 2008)
Manufacturing	Geothermal loop install	• Burning of excess plastic materials can produce toxic gasses (CHEJ 2004) • Greenhouse gas production from well drilling or excavating machines
	Assembly of heat pump	• Scrap materials can end up in landfills
	Installation of heat pump	• Scrap ducting or other materials can end up in landfill
Transportation	Transport of raw materials to manufacturing facilities	• May ship by train, truck, boat or air depending on where raw materials are sourced from – all methods produce greenhouse gasses

	Transport of plastic tubing to job site	• Likely to ship first by truck or train to distribution center, then ship by truck to job site – both producing greenhouse gasses
	Transport of heat pump to job site	• Likely to ship first by truck or train to distribution center, then ship by truck to job site – both producing greenhouse gasses
Usage	Electricity used to circulate fluid through loops, circulate air through house, and supplement additional heating/cooling as needed	• Electricity production produces greenhouse gasses
Disposal	Replacement of heat pump	• Entire heat pump may end up in landfill • Portions could be recycled depending on ease of disassembly
	Replacement or repair of geothermal field	• Burning of plastics can produce toxic gasses (CHEJ 2004)

Table 4: Summary of potential environmental impacts during product lifecycle

Category	**Description**	**Potential Environmental Impact**
Materials	Plastic tubing for geothermal loop	• Production of toxic waste in both manufacturing and disposal (CHEJ 2004)
	Replacement of heat pump	• May end up in a landfill
	Scrap materials	• Scraps produced during manufacture or installation may end up in a landfill
Energy	Production energy usage	• Heat, electricity, and transportation are all sources of energy used in the production of the raw materials for the system

	Distribution energy usage	• The distribution of the raw materials to production facilities, components to the manufacturing facility, and finished product to the job site all are producers of greenhouse gasses
	Installation energy usage	• The installation of the system relies on well drilling and excavating – both which produce greenhouse gasses
	Use	• Consumes electricity during usage phase
	Recycling energy usage	• If the product needs to be repaired or discarded, greenhouse gasses are produced
Chemicals	Plastic tubing production or disposal	• Production of toxic waste in both manufacturing and disposal (CHEJ 2004)
	Production of working fluid for geothermal loop	• Certain refrigerants are toxic to produce (US EPA 2013)
	Silicon components inside heat pump	• Toxic byproducts of semiconductor production (US EPA 2008)
	Greenhouse gasses	• Produced from installation machinery and transportation used between stakeholders
Other		•

Table 5: Organization of environmental impacts into four categories

Stakeholder	**Interactions with**	**Possible Reductions of Environmental Impacts**
Raw material suppliers	Shipping companies	Can choose most efficient shipping methods to reduce greenhouse gas production

	Manufacturer of loop tubing	Can choose most efficient shipping methods to reduce greenhouse gas production
	Manufacturer of heat pump	Can choose most efficient shipping methods to reduce greenhouse gas production
	Scrap companies	Can insist that the most environmentally friendly scrap methods are used
Shipping companies	Raw material suppliers	Can choose most efficient shipping methods to reduce greenhouse gas production
	Manufacturer of loop tubing	Can choose most efficient shipping methods to reduce greenhouse gas production
	Manufacturer of heat pump	Can choose most efficient shipping methods to reduce greenhouse gas production
	Supplier/installer of the system	Can choose most efficient shipping methods to reduce greenhouse gas production
	Scrap companies	Can insist that the most environmentally friendly scrap methods are used
Manufacturer of loop tubing	Raw material suppliers	Can insist that methods of obtaining raw materials produce as little waste and greenhouse gasses as possible
	Shipping companies	Can insist that the most efficient shipping methods are used to reduce greenhouse gas production
	Supplier/installer of the system	Can choose most efficient shipping methods to reduce greenhouse gas production

	Scrap companies	Can insist that the most environmentally friendly scrap methods are used
Manufacturer of heat pump	Raw material suppliers	Can insist that methods of obtaining raw materials produce as little waste and greenhouse gasses as possible
	Shipping companies	Can insist that the most efficient shipping methods are used to reduce greenhouse gas production
	Supplier/installer of the system	Can choose most efficient shipping methods to reduce greenhouse gas production
	Scrap companies	Can insist that the most environmentally friendly scrap methods are used
Community developer	Supplier/installer of the system	Can insist that methods are used to reduce waste and greenhouse gas production
	Homeowners	Can offer geothermal as the only heating/cooling option, thus ensuring its use
Supplier/installer of the system	Manufacturer of loop tubing	Can insist that production techniques produce the least amount of waste and greenhouse gasses
	Manufacturer of heat pump	Can insist that production techniques produce the least amount of waste and greenhouse gasses
	Shipping companies	Can insist that the most efficient shipping methods are used to reduce greenhouse gas production
	Community Developer	Can use methods that product little waste and greenhouse

		gasses
	Homeowners	Can use methods that product little waste and greenhouse gasses
	Scrap companies	Can insist that the most environmentally friendly scrap methods are used
Homeowners	Community developer	Can insist that methods are used to reduce waste and greenhouse gas production
	Supplier/installer of the system	Can insist that methods are used to reduce waste and greenhouse gas production
	Scrap companies	Can insist that the most environmentally friendly scrap methods are used
Scrap companies	Raw material suppliers	Can use the most environmentally friendly scrap methods
	Shipping companies	Can insist that the most efficient shipping methods are used to reduce greenhouse gas production
	Manufacturer of loop tubing	Can use the most environmentally scrap methods
	Manufacturer of heat pump	Can use the most environmentally scrap methods
	Supplier/installer of the system	Can use the most environmentally scrap methods
	Homeowners	Can use the most environmentally scrap methods

Table 6: Interactions between stakeholders

Appendix 3. Detailed Impact Assessment

A life cycle inventory was conducted and condensed into four damage categories: Human Health, Ecosystem Quality, Climate Change and Resources.

Impacts associated with manufacturing the systems and the associated infrastructure are represented by Figure 17.

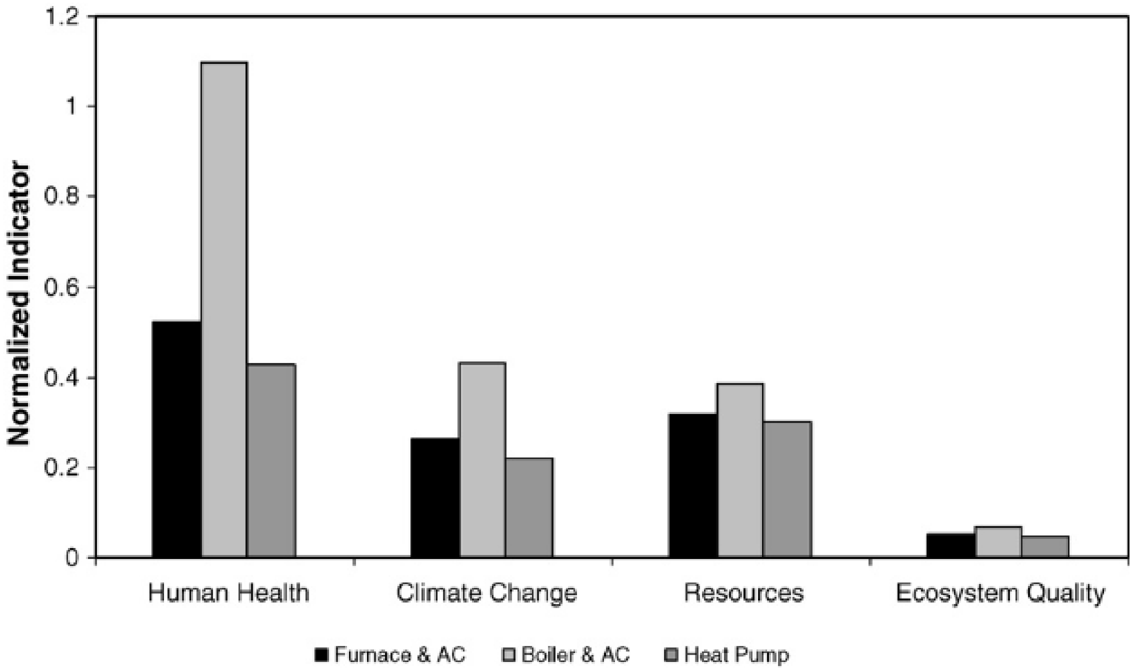


Figure 17: Manufacturing impacts for heating/cooling systems.

The boiler and the AC system have the highest impact in all categories primarily because of the high impacts due to the manufacturing of the metals used in the system. The impacts due to the air to air heat pump are the lowest in the four categories since a single appliance fulfills both the heating and the cooling.

The life cycle impacts over the study period including energy use for the three systems at the four locations are presented in Figure 18-Figure 21 and show the relative life cycle impact for the three systems in terms of respiratory inorganics, aquatic ecosystem, global warming, and non-renewable energy categories.

The majority of the impact in the respiratory organics category is from SOx and NOx which is released during the extraction and distribution of natural gas for the furnace and boiler systems, or from coal-generated electricity for the heat pump system.

The impact in the aquatic ecosystem category is mainly from the oil emissions during natural gas manufacturing and due to dispersion of metallic ions during manufacturing of the system appliances. As the heat pump uses fewer metals, its impact is lower.

The extraction and combustion of fossil fuels for energy is the single largest source of impact in the global warming and the non-renewable energy categories (V. Shah 2007).

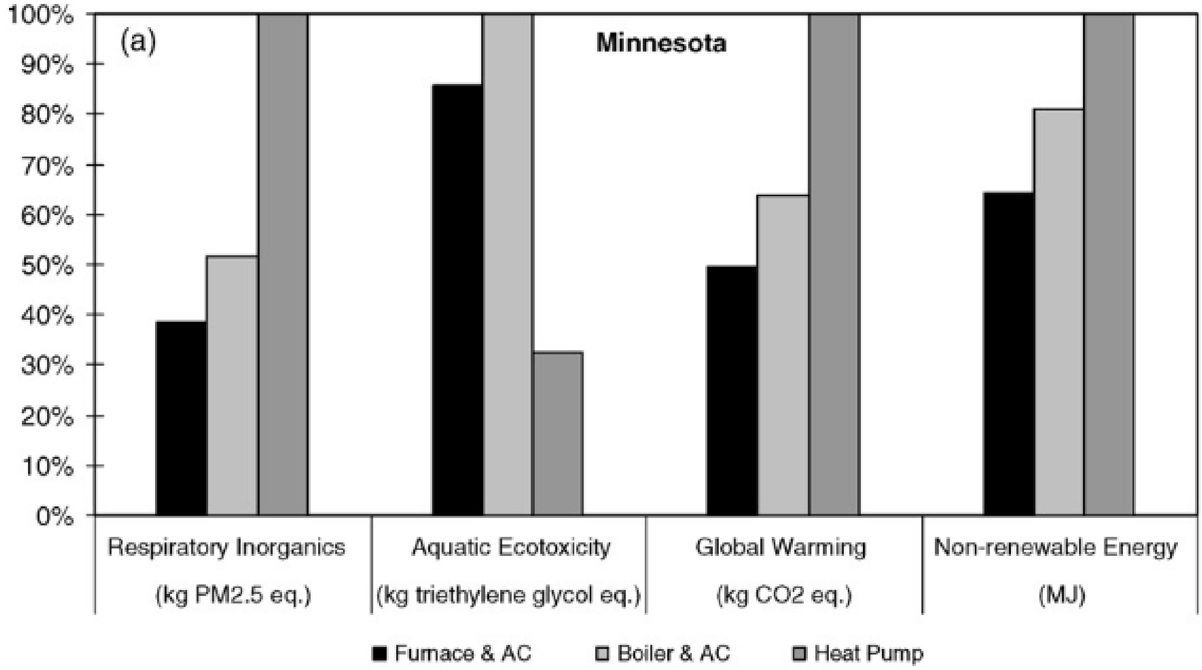


Figure 18: Lifecycle impacts of heating/cooling systems in Minnesota.

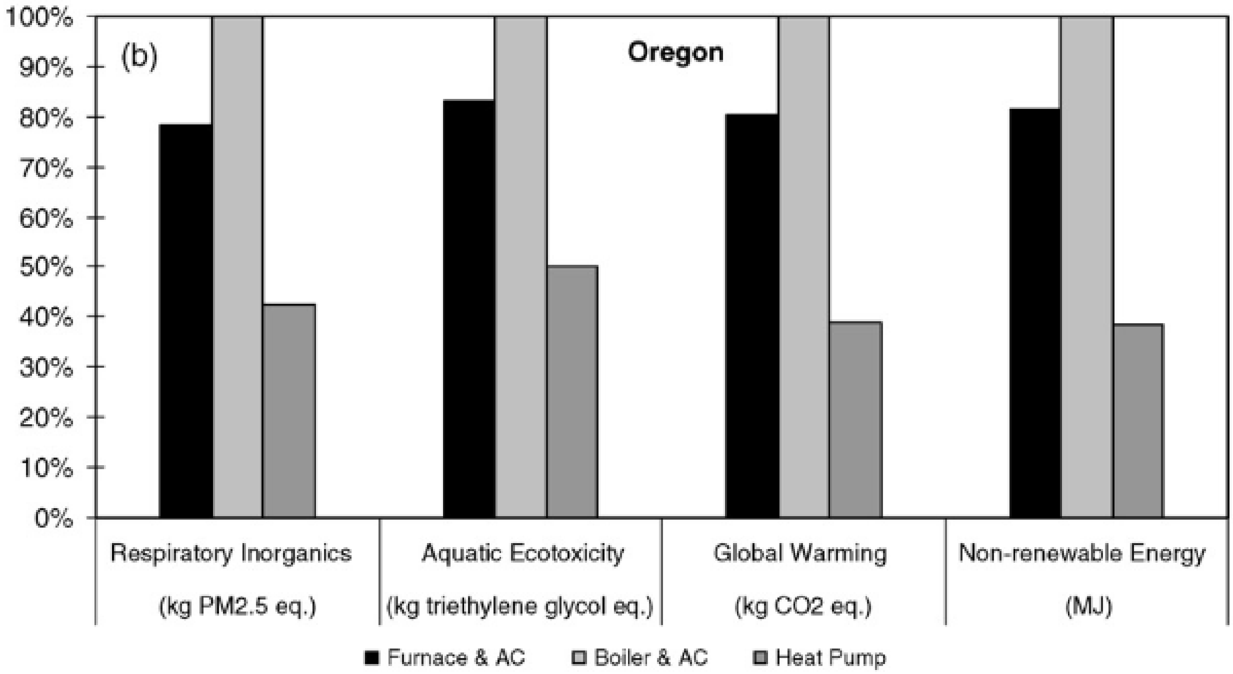


Figure 19: Lifecycle impacts of heating/cooling systems in Oregon.

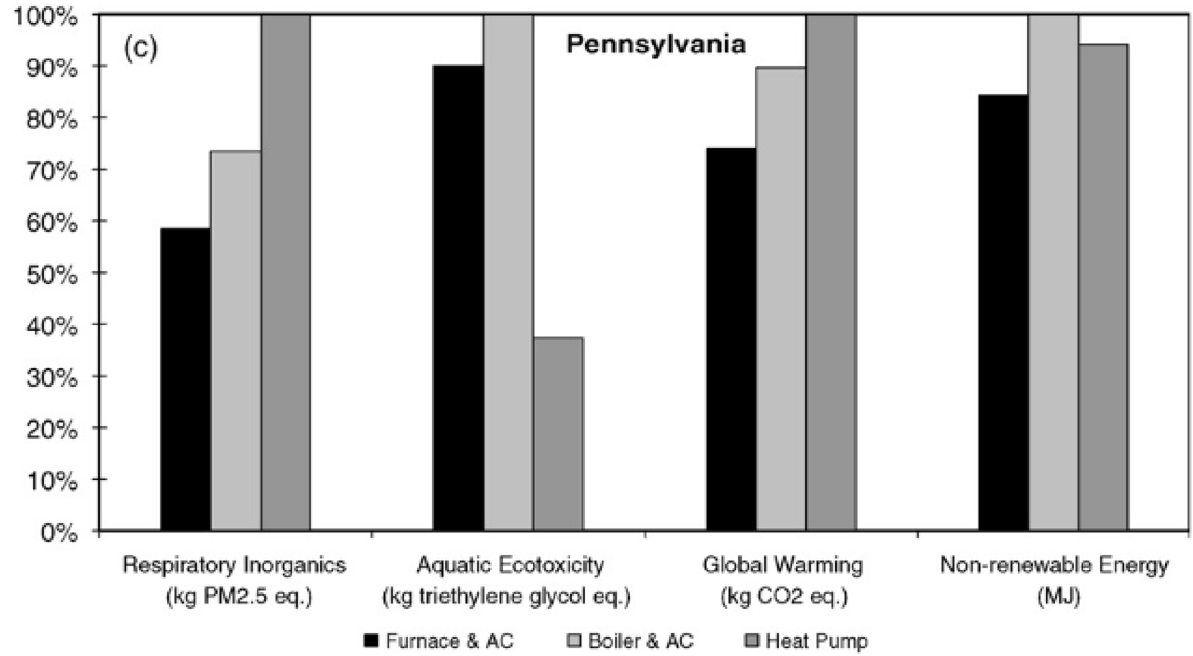


Figure 20: Lifecycle impacts of heating/cooling systems in Pennsylvania.

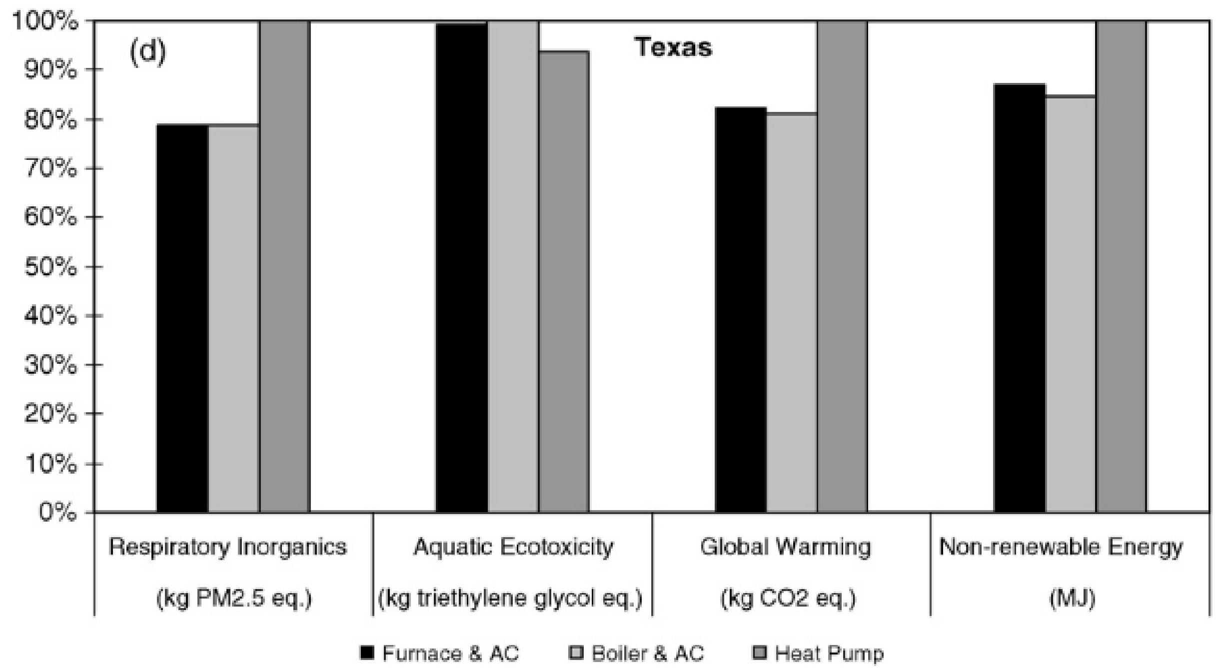


Figure 21: Lifecycle impacts of heating/cooling systems in Texas.

Allocation of impacts in the damage categories is shown in Figure 22 - Figure 25 for the four regions. Minnesota has the highest impacts overall for all three systems because of its higher heating loads and its dependence on coal for electricity. Regional climate and energy generation have a significant effect on the total impacts.

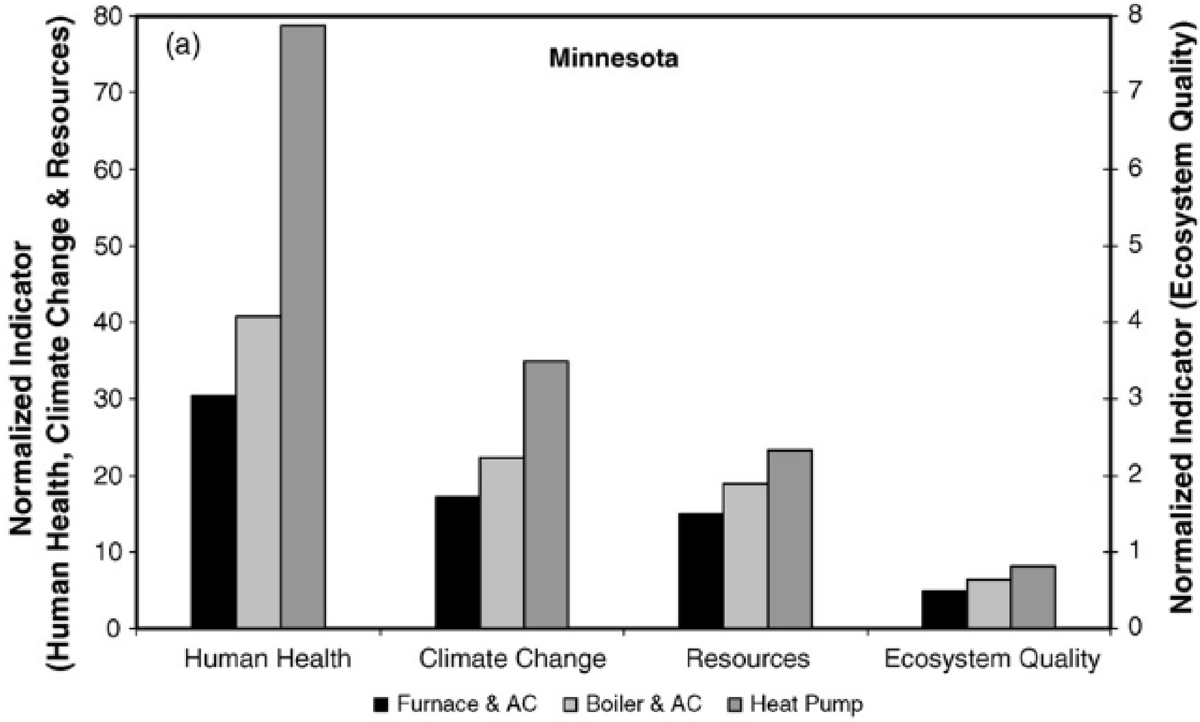


Figure 22: Negative impacts of heating/cooling systems in Minnesota.

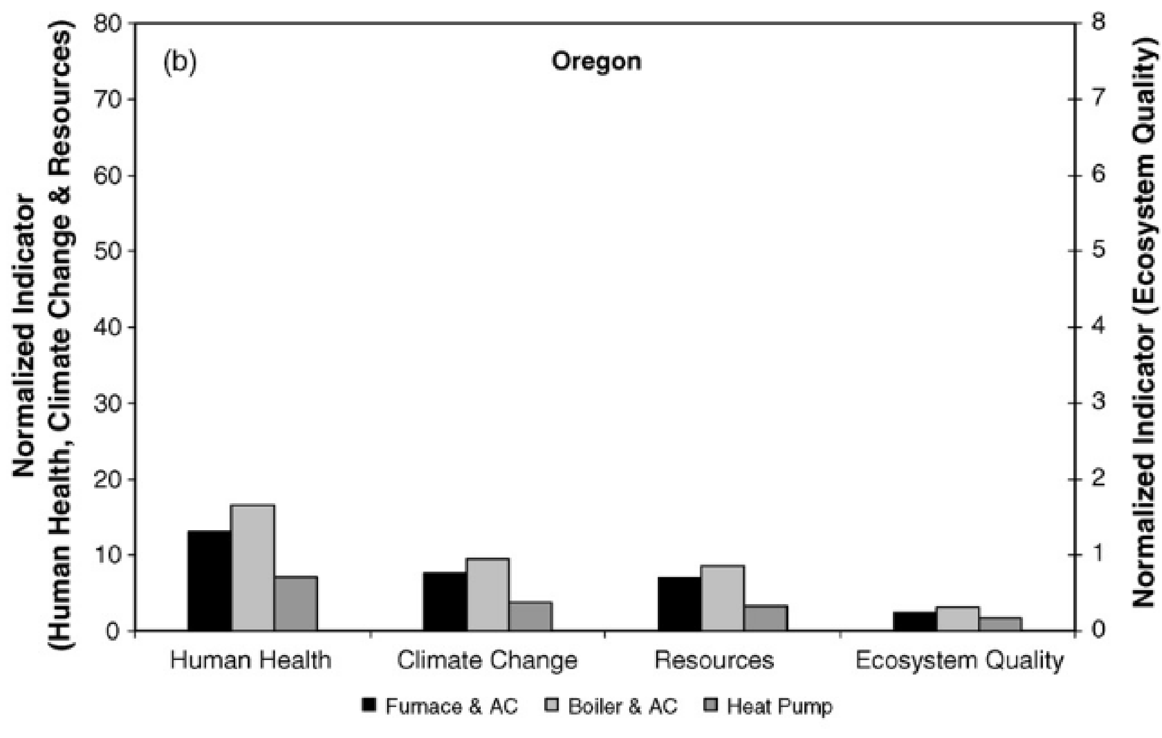


Figure 23: Negative impacts of heating/cooling systems in Oregon.

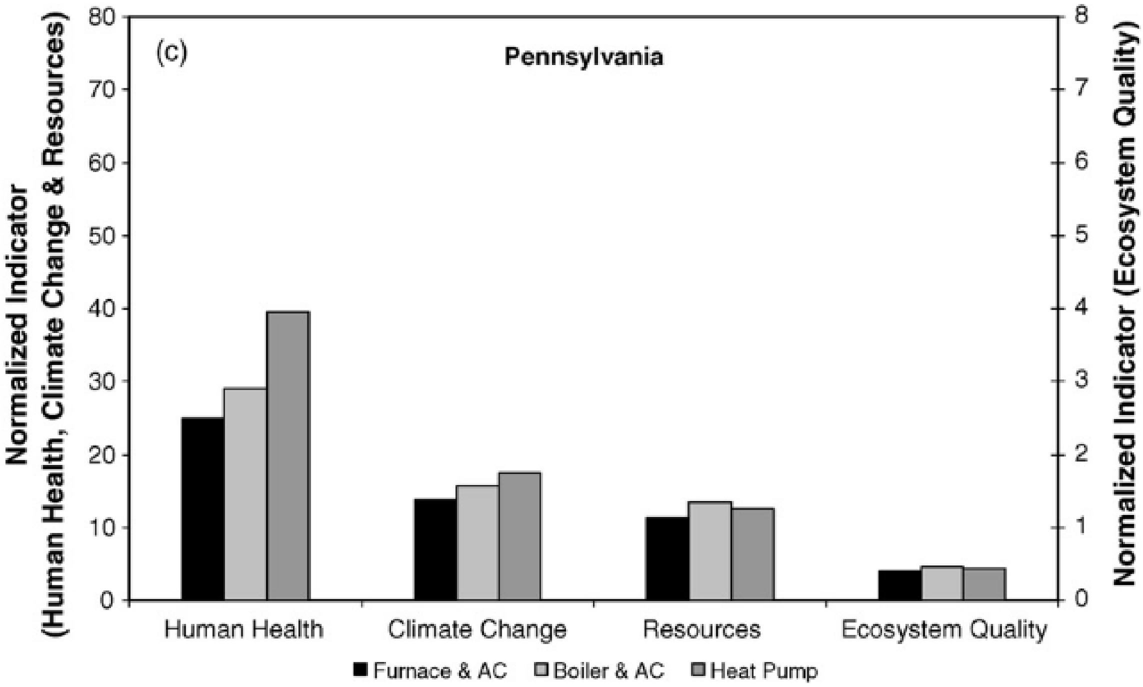


Figure 24: Negative impacts of heating/cooling systems in Pennsylvania.

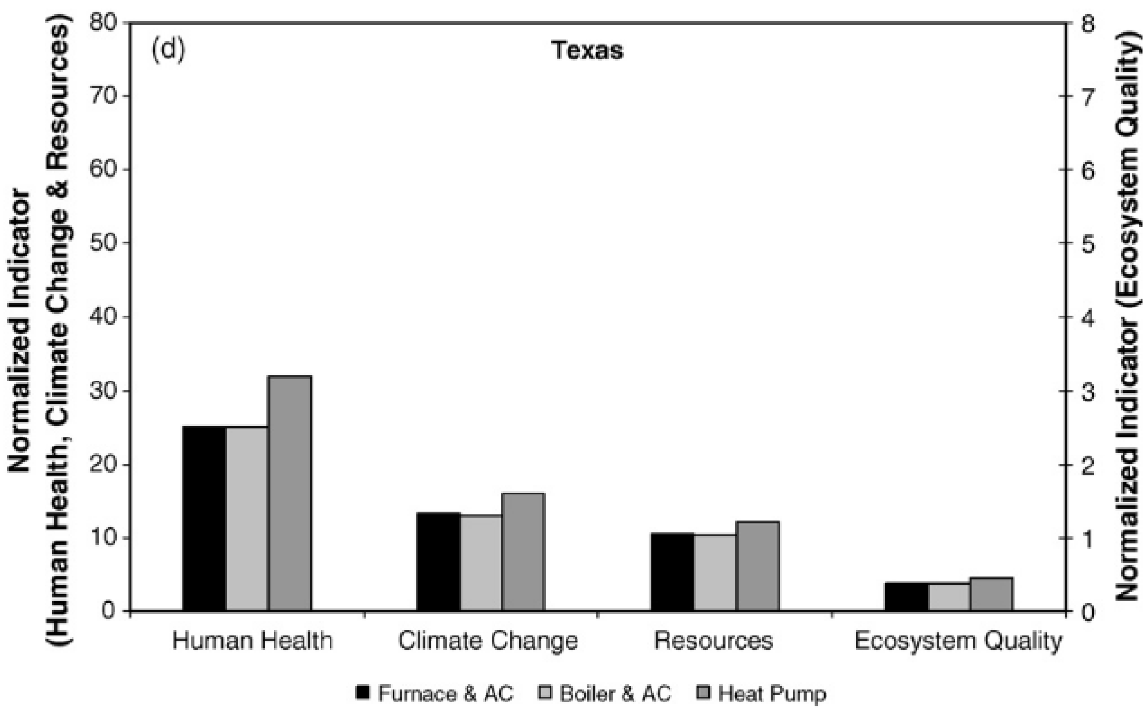


Figure 25: Negative impacts of heating/cooling systems in Texas.

Appendix 4. Interview Summary

Interview 1 Template: Personal Consumer

1. **Introduction:**
   a. What is your relation to me?
   b. I would like you to be honest and forthright with all answers provided. If you have any questions, please ask. Do you understand?
2. **Kick Off**
   a. What is your age, occupation and housing status?
3. **Rapport**
   a. Have you ever built a new house or lived in a newer home? Would you like to at some point?
   b. Who is the primary breadwinner in your household?
   c. Who is in charge of paying bills in the household?
   d. When something breaks, who is the person who ends up fixing it? If no one in the house, who typically makes sure someone is called to fix it?
4. **Grand Tour:**
   a. What is your biggest home expense in the summer month?
   b. What is your biggest home expense in the winter months?
   c. What do you think is your biggest energy user in the household?
   d. How do you heat your home?
   e. How do you cool your home?
   f. If you built your house, did you have any say in why you chose your heating and cooling system?
   g. Do you think you have a good system? Why do you think so?
   h. Do you know anything about how the system works?
   i. Do you know of other ways homes can be cooled and heated?
   j. Would you ever go out of your way to install a different kind of system?
   k. What would make you do it?
5. **Reflection**
   a. Why do you think you are being asked these questions?
   b. Do you think any of your answers would have changed now at this point?
6. **Wrap Up**
   a. Any Questions?

Summary of Interview Results

Most people, even the head of households, are not that interested in what type of system they have. They judge their system based on the performance results and whether or not they have any issues with it. Knowledge base about the systems varied a lot as did willingness to fix things. This seems to point to the fact that people choose their systems because they are put right in front of them and are told the quality is good. It seems like the end consumer is more about a PR campaign than actual implementation.

Interview #1 Results: All answers were scribed in short during process and reiterated here. Wording is not necessarily verbatim.				
Question	What is the purpose of the question	Interview #1	Interview #2	Interview #3
What is your relation to me?	To establish boundary of interview	Friend	Coworker	Former Coworker/Friend
I would like you to be honest and forthright with all answers provided. If you have any questions, please ask. Do you understand?	To make sure they don't try to give an answer I want to hear.	Yep	Yep	Yes
What is your age, occupation and housing status?	To establish demographic	25, Media Specialist, Home Renter	32, Engineer, Single Family Home, built 2003	45, Engineer (retired), built 2000
Have you ever built a new house Would you like to at some point?	To learn if they have ever been unsatisfied with predetermined layouts or are typically complacent with what they have available.	No, yes I would some day	I live in a newer home now, I think they are all the same regardless	I bought my house as the subdivision was being built.

Who is the primary breadwinner in your household?	To find out if they are person who considers themselves the authoritative figure in the house.	I live with roommates. We all are.	I am	Nobody technically, but me
Who is in charge of paying bills in the household?	To find out if they think they are the responsible one in the house.	I pay them, but my roommates pay me	I have it all set up online to come from our joint account. So we both do.	My wife primarily
When something breaks, who is the person who ends up fixing it? If no one in the house, who typically makes sure someone is called to fix it? What is your biggest home expense in the summer month?	To find out if they are typically a decision maker in the house. Also to learn how many people are capable of home repair.	Usually the landlord is supposed to, but a lot of times I will just ask my boyfriend	If it is a small task, I will do it, but I won't touch anything with gas, water or electrical	I typically have replaced everything in my old house. I haven't had any major work on my current house.
What is your biggest home expense in the winter months?	The answer should be home heating. This will show if they are actually cognizant of that.	The gas bill or water bill, but the water is high all the time	The gas or electric because of the winter and Christmas lighting	Probably the gas bill is my guess

What do you think is your biggest energy user in the household?	This gives perspective about how much they interact with their house and the monthly utilities. Also their understanding of what energy is.	Probably our water bill. Probably using the washing machine and showering all the time.	I think it depends, but I think the furnace and A/C	My kids. Maybe the lights.
How do you heat your home?	If they know anything about their home heating system.	A furnace. I don't know. Gas	Natural Gas	Natural Gas
How do you cool your home?	Same as above	Sometimes we use the air conditioner	A/C	A/C
If you built your house, did you have any say in why you chose your heating and cooling system?	How much do they think about their homes in general. To see if they even thought about different options or asked.	I didn't. I probably wouldn't care.	I didn't. I think you get options and upgrades. I would most likely just take the best one with quality that wasn't overly expensive	I went with the base package they offered. You were not allowed to nitpick all the little details.
Do you think you have a good system? Why do you think so?	To start to hint that I am interested in this topic.	No because our bill is really high.	I think so. We haven't had any problems with it so far.	Our bill is pretty low compared to my old house and I haven't had any major problems.

Do you know anything about how the system works?	To see their basic understanding of the system	No nothing at all	It's a heat exchanger with natural gas that heats forced air. The air conditioner is a compressor I think that chills air similarly.	It runs on natural gas. It heats the air with channels that are filled with exhausted fuel to heat the air.
Do you know of other ways homes can be cooled and heated?	To understand their depth of knowledge in this area	No not really	I know of electric furnaces, geothermal. I think geothermal is not really used though.	Electric furnaces but I think those actually cost more. Some people also use propane but that is also expensive.
Why do you think you are being asked these questions?	To see what they are actually thinking at this point about me and the interview?	Something about heating homes	You are researching home heating?	I think you are looking at heating costs for homes
Do you think any of your answers would have changed now at this point?	To see how they feel about me implying that an answer could be right or changing at this point.	No why?	No	No
Any Questions?	Follow Up	Nope	No	No

Interview 2: The home builder

1. **Introduction:**
    a. What is your name?
    b. What is your role at the company?
2. **Kick Off**
    a. How many homes do you build in a year? What areas?
3. **Rapport**
    a. When building an entire neighborhood, how much do you typically try and do simultaneously?
    b. Do you build each house, one at a time or all at once?
4. **Grand Tour:**
    a. What kind of HVAC systems do you currently install into the majority of homes you build?
    b. Why do you choose this system (and brand)?
    c. If there was an alternative technology to conventional forced air, what would the benefits have to be and what would the concerns be to implementing in new construction?
    d. Ask them to elaborate on their answer
    e. Ask if they know what geothermal is and Introduce geothermal if they don't. Ask them what they think about it?
5. **Reflection**
    a. Do you think that your customers would be interested in geothermal systems?
    b. Why would they feel this way?
    c. Who do you think can drive change into housing designs?
6. **Wrap Up**
    a. Ask for contact info if not available already.
    b. Ask if they would be willing to do a follow up interview with a concept proposal (or survey) i.e. feedback

Summary of Interview Results

Seven home building companies were contacted that are known to operate in the area. Of these seven, two consented to giving interviews for this project. Overall, the general feeling amongst the home builders was that they are interested in providing options to home buyers that are cost minimal and highly reliable. Options that some consumers may want (i.e. niche markets) are not what they are interested in because of the large variance in desire and low return on effort. The director of purchasing (buyer) appears to be the person who determines what systems are currently installed on site. This is also the person who receives literature from the industry about new concepts and proposal to changes things in home design. It seems it all comes down to having a tried and true system that is as cheap as a current system with quality seal. It seems like the purchasing director is the most important person at the company as far as ability to make change.

Interview #2 Results: All answers were scribed in short during process and reiterated here. Wording is not necessarily verbatim.			
Question	What is the purpose of the question	Interview 1: Edwin Allen Homes	Interview #2: Need Doris's stuff
What is your name? What is your role at the company?	Identify	Penny, Allen Edwin Homes	Name: Greg Henderson Phone: 810-688-3491 General Contractor
How many homes do you build in a year? what areas?	Establish validity	I am not sure on the exact volume, but we build all over the state of Michigan	4-6
When building an entire neighborhood, how much do you typically try and do simultaneously? Do you build each house, one at a time or all at once?	Understand the basics of their job routine	I am not really sure about that I have a name for you if you want. We don't install the furnace ourselves. We actually source that work to a contracted company.	n/a
What kind of HVAC systems do you currently install into the majority of homes you build? Why do you choose this system (and brand)?	What is their thought process in product selection to date?	We build the basic boring tried and true systems. We don't do anything fancy like steam or solar or anything like that.	Natural Gas in urban areas Propane in rural areas
If there was an alternative technology to conventional forced air, what would the benefits have to be and what would the concerns be to implementing in new construction? Ask them to elaborate on their answer	What is their initial feelings on new technology	That isn't really in our market. We like affordable income houses with the basc systems.	Doing a current house with a Hydronic system, which is geothermal, with heated floors. The wells were put in the driveway and are vertical open loop. The builder usually has a size and brand of furnace and AC to use. Generally he asks the heating contractor. The builder trusts the heating contractor because the contractor knows which systems he has had problems with. Furnaces are highly technical. Size is determined by number of window openings, door openings, insulation, etc. A lot of decisions are made by the heating contractor.

Ask if they know what geothermal is and Introduce geothermal if they don't. Ask them what they think about it?	Understand their knowledge as it pertains to proposed concept	I don't think that will really work for us. This isn't like Florida where that might work better. In Michigan we have seasons and I don't think that would work. (I don't think she understood what geothermal was)	Greg has done a few houses with geothermal · expensive · now better at keeping up with the cold · has lived in a house with geothermal · AC works excellent · decision highly depends on the budget for the new home.
Do you think that your customers would be interested in geothermal systems? Why would they feel this way?	Understand their opinion on their key stakeholder value	I don't think we are in the market of people who want those kinds of features on their homes. Our houses are more standard.	See above
Who do you think can drive change into housing designs?	Same as above	Our director of purchasing is the person who orders and selects the systems we use. Also our production manager oversees the job site.	n/a
Ask for contact info if not available already.	Info	Person in charge production: Scott Uslh 269.998.2814 purchasing Production and overseer: Craig Russel production and field operations 269.720.4166	Above info
Ask if they would be willing to do a follow up interview with a concept proposal (or survey) i.e. feedback	Follow up	Yes	Yes

Interview 3: City Planner

Interview with Randy Byrne, State of Michigan

Background: Randy was the city manager for Almont for 5 years, the city manager for Grand Blanc for 30 years. He is now working for the State of Michigan Treasury Department working with financially distressed communities (Flint, Allen Park, Benton Harbor, Hamtramck, etc.) with the goal of getting them back to local government control rather than state emergency manager control.

Interview:

Doris: Do you know what geothermal is?

Randy: Yes, we were looking at it for the Grand Blanc City Hall but the numbers were too high to put in the system. They eventually would have got their money back, but the payback was not attractive.

The problem is Can you afford to make the investment? I will give you an example: There was one community who was approached by a company to do an energy evaluation of all equipment. The company had a financing arm. The company study showed on paper that there was a $ value to update equipment with more energy efficient equipment. The city signed the contract. Unfortunately the city has not seen the energy efficiency. So the city decided to not make the payments to the company. There now is a lawsuit. It could be that the lack of payback was due to lower natural gas cost. How do you know that the savings is there up front? Are the numbers really reliable? Are they really going to pay off?

Grand Blanc was also looking at LED lighting inside of city hall. So they got some example bulbs but did not see the longer life. So there is supposed to be a different life expectancy on LED bulbs. Improvements are stated, but are you really better off?

Doris: How do we make geothermal more attractive to builders / buyers?

Randy: Tax break for builders. Is there a pay back? Could you market to energy efficient people? I can see it. But developer has to have the financing in place. Look at all the builders that went bankrupt. Builders are very risk adverse right now. This will pass given time.

State / Federal Government - grants

Federal Government has the where withal to do.

Doris: Can you think of any options at the city / state / federal levels?

Randy: There is a real reluctance in this country to invest in infrastructure. Governments can't find the answer to bring roads (for example) up to where they need to be. Perhaps a public / private partnership. Geothermal makes sense on paper, but there is a lack of motivation. I don't know if we have the Edisons and Fords to get new technologies going. It is difficult to get people to invest in infrastructure (roads, utilities). Look at China and India. There is no reluctance to invest in infrastructure there. The U.S. is stuck in a rut. New energy would fall under that banner. We need big thinkers. China is building high speed rail, highways, and dams. For local governments, it is hard to rebuild a block of subdivision pavement. U.S. does not lead in infrastructure.

This would not be funded at the state level. They have other big priorities, and have no resources to deal with anything beyond the end of their nose. They may be able to provide a financing vehicle with the bulk of the funding coming from the federal government.

Local level: Probably more doable in a smaller setting, but would take visionary leadership and cost / benefit analysis. It is not farfetched that a local government with city management would do this . However, would the bond market finance it?

There is a failed movie studio in Allen Park. The local government is on the hook to pay for the property. Local government would want to make sure that they do not go bankrupt.

Local governments are adverse to risk. The Detroit Bankruptcy has sent shock waves through the bond market. Local governments would have to either finance internally (if they had the money to do so) or they would need to go to the bond market.

The Reverse Osmosis System for Grand Blanc.

Grand Blanc put RO system in Grand Blanc in 2004. They are one of four cities treating drinking water. Grand Blanc had a lot of well water, but the water had high levels of magnesium and iron.

Two technologies were considered: RO and Lime Softening.

Lime Softening would require a much larger building which would have pools of water and have to be operated 24/7 with a minimum of five people. It has a lime scale by product that is tough to get rid of.

The RO required a smaller building. Build on two sites. Not 24/7 operation. Instruments are monitored 24/7, and people notified electronically. By product is very clear and goes to sanitary sewer to Montrose waste water treatment plant. The system is flexible. It can be made harder or softer.

Filters are supposed to last five years, and are getting double the life, so it is cheaper than anticipated. Grand Blanc is getting a grant to allow for automatic meter reads, and filter changes

The RO was $4.5M financed over 20 years. It is now 50% paid off. They sold bonds -- full faith and credit general obligation bonds. It was financed though the water revolving fund. This is a 2% interest rate bond from the State of Michigan.

Could this special financing or something like it be used for geothermal? It is a question for the DEQ.

If you have more questions, you can call me back on my cell phone.

Interview 4: Feedback from builder

Doris: Our project idea is one where a subdivision of 10 to 100 houses shares a heating and cooling system. Have you ever heard of anything like it?

Greg: No, I have never heard of anything like it.

Wells are a closed loop system. Geothermal can lower the ground temperature by several degrees.

The system for the house that I am currently working on is a geothermal system, installed by Denny's Heating and Cooling. It is a Geothermal II, and has a Boiler Buddy, storage unit for geothermal. It is a big tank. 7 feet tall and 30 inches in diameter and is hot to the touch.

Doris: What kind of builder builds subdivisions?

Greg: Huge conglomerates like Poulte. It has been a while since any of these subdivisions have been built up. Big subdivision builders tend to stretch out payments to subcontracters (as in if you do these next three houses, then I will pay you for the last three that you did).

These conglomerates will buy a 80 acre field, and work 24 hours per day (all day and all night). 50 to 100 to 300 houses will go up in a matter of a few months. i.e. these builders are interested in speed, so that they can sell the houses quickly. They subcontract locally. These conglomerates tend to pull out of states where the market is not good.

Doris: What is their relationship with the municipality? Do they get tax breaks from the property or funding to put in roads?

Greg: I don't know if they get tax breaks.

The builder will pay approximately (per house):

- $2000 to $3000 for sewer taps from municipality
- $500 for city water from municipality
- $1000 to $1500 for natural gas from utility (e.g. Consumers)
- $500 to $1000 for electrical (which is run underground for large subdivisions) from utility (e.g. DTE)
- permits
- zoning special permissions for square footage and frontage

The general contractor pays for all of the subdivision roads and driveways.

(aside) A friend of his built Devonshire in Lapeer, an assisted living center.

Concerning the house that Greg is working on currently:

The house has geothermal with hydronic in the floors.

It has a natural gas system as backup heat to the geothermal, and it also heats the pool, the area around the pool (to melt the snow) and the driveway (to melt the snow). The natural gas furnace has an 8 inch exhaust and 1.2 M BTU. In the driveway, the heating tubes heat through two inches of concrete and 1 1/2 inches of bluestone to melt the snow.

It is has 5 1/2 inch wide hardwood flooring that has the hydronic tubes underneath. The hydronic system has glycol as the fluid.

It is at least a $5 million home.

It has a pizza oven/ bread baking oven that is fire brick lined.

Interview 5: Feedback from city planner

Doris: Have you ever heard of a subdivision project that had a common heating / cooling system?

Randy: Personally, I have not. But I am sure they exist. I am sure there is something out there like this. It is not uncommon for an entrepreneur to try this type of thing. I am sure they exist out there. I am positive there is a community with municipal buildings.

Doris: What kind of municipality would do a project like this?

Randy: It is more useful to ask "Under what circumstances would a municipality do this?"

1) A municipality would tend to do this who has a system that is outdated, in need of expensive repairs, or is inefficient.
2) Implementation accompanied by a grant or low interest loans – this is usually the stimulus that gets a municipality to do a project that has up-front cost with a longer term benefit.

Three years ago, much money was provided to the state of Michigan. The states did grants to municipalities. I know that some of these were geothermal. The Energy Office of the state of Michigan handled the grants.

We submitted and won a grant for new streetlights from Perry to Holly Roads in Grand Blanc. The community had to do the engineering. They submitted to the state to prove gains in energy efficiency for a $120,000 grant.

The state provided: grant money, contract administration and documentation to the federal government, guidance on the project. The supplier of the lighting had to be an American supplier or a qualified supplier from a foreign country. The company we had was based in Sarasota, Florida. The state held a couple of workshops. Grand Blanc had to provide the documentation to prove that they met the requirements.

Doris: Who would champion a project at a local municipality?

Randy:

1. Someone who takes a broad perspective in operations
2. The city manager who oversees all departments and all operations
3. City Council Person – with expertise or knowledge of systems and production management
4. Someone who knows about great opportunities and who has information on the grants.
5. Department head who has knowledge – e.g. the Reverse Osmosis Water Project
6. Knowledgeable Citizen who brings it forward to the city council.

Doris: How did Grand Blanc find out about the lighting project?

Randy: The Michigan Municipal League sent information out to Randy on the stimulus program. They provided details of the program. The MML was assigned by the Energy Department to provide information to local units. They conducted informational meetings on what the Federal Government was looking for.

The Feds developed priorities.

The States put it into a format.

The municipalities picked projects that they would submit for funding.

Grand Blanc wanted to do a project that would provide a long term benefit. They got LED fixtures so it saved dollars at the same time.

Grand Blanc paid engineering cost, and in-house staff time, the government picked up the rest.

Need to have dollars, but also mesh with municipality goals. The municipality can justify it if they can get grant money.

Randy suggests that I call the Energy Department. He will help me to find a contact.

Appendix 5. Concept Generation

Double Reverse Concept Generation

Functional Requirements	Worst Design	Reverse (Optimal) Design
Installation of System	• System design is not standardized (every installation is unique) • System installation requires more experience with tradesmen	• Standard design practices with common parts • Installation does not require new trade
Installation Cost Neutrality	• Cost neutrality requires lots of red tape and is difficult to implement • Cost neutrality requires timeframe for reimbursement	• Installation requires approvals and paperwork in line with other services at home (i.e. water, gas, etc)
Lower Operating Cost	• n/a	• n/a
High Reliability	• Reliability requires higher capital cost and multiple redundancies to verify. • Design isn't intrinsically simplified to reduce potential issues • High frequency of maintenance • Design is reliable, but does not perform as well as conventional	• Design is intrinsically simplified to reduce potential concerns • System does not require frequent maintenance • Design performs as good or better than conventional
High Quality	• Quality of design requires costly materials or materials that are hazardous	• Design utilizes affordable materials that minimize quality concerns for the desired life of the system
Inclination of Home Builder to Provide	• Home builder is disenfranchised by participating	• Homebuilder is able to participate with minimized economic impact
Alternative Fuel Resource (to fossil fuels)	• Resource is not readily available. • Resource will require development and infrastructure to support demand • Resource is not environmentally friendly	• Resource is readily available or could be with minor infrastructure • Resource is more sustainable that conventional resources

Additional Concept Ideas

Geothermal Community Systems

The concept would essentially take the best parts of the Ball State University underground pumping system and implement it at a neighborhood level. Supply and return lines would run through shared well systems that have a two-joint interface for every home that interfaces. This would essentially put all homes in the neighborhood in a parallel fed system that could be used for heating, cooling and potentially water feed lines as well. In this case, the majority of the parts are owned by a municipality or housing association and only the heat exchanger and back up heater/cooler is needed at the home.

Magic Number Privately Shared Systems

A network of homes would share a system of wells that are isolated to each home. The shared asset would be in installation, maintenance and location. The strategy would be to find the optimal number of homes to be connected in order to keep the cost to a minimal.

Basement System Location

At time of housing design, wells are drilled in basement area. The purpose of this would be to integrate land surveying of house foundation with well drilling. Also this would incorporate land space for wells into housing footprint.

Sub-Terra Housing

House design would incorporate more earth around the perimeter of the house either by burying it below the surface or by creating a hill around the home. The purpose of this would be to lower the cost of the system needed to heat the home. This would potentially remove the need for any change in technology as the overall system need would shrink drastically.

Pond System

In order to minimize the cost of the well system, homeowners could have the system use a pond or lake. This presents the easiest way of sinking or sourcing through conduction of the waterbed. As well, with horizontal pipes laying in a pond, there would be no issues with footprint or large costs for site surveying.

Federal/State/Municipal Tax Incentives

All capital costs of the system would be covered upfront with funding. This could happen at multiple levels of government in addition to the current federal incentive.

Carbon Tax Incentive

The use and operation of conventional furnace systems would have a monetized tax for use. This could either occur at time of purchase based upon the size and efficiency of the furnace or it be attached to the cost of fuel.

Federal/State Incentives for municipal controlled systems

Communities would receive support either by funding or credit to build a large system. This would be an hybridized concept of incentives and Ball State.

Create Geothermal Heating and Cooling as a Utility

Through legislation (at any level) require all new housing to integrate a utility based system that is regulated for price. This is an active legislation technique to implement the ball state concept.

Ductless Homes Electrical Heating

The scope of this project would be to incorporate electric heating systems into every room of the household. The primary benefit of a system like this would be that it removes any need for a distribution system. As well, rooms could be controlled independently allowing the home owner to use their system more efficiently. This system cost impact would be dependent on their desired level of control (i.e. size of smaller systems).

Appendix 6. Concept Selection Appendix

Quality Function Development (QFD)

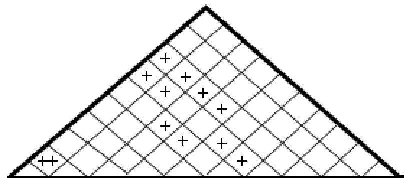
Alternative Heating and Cooling System

Relation Between Engineering Specs

++ Very Strong

+ Strong

No relation



	Weight (1-10)	Total System Cost	Payback period	Lifetime of Indoor System	Lifetime of Outdoor System	Heating and Cooling Capability	Issues per Year	Percentage of Homes in Community Being Built with Geothermal	Reduction in Materials	Reduction in Emissions	n/a	Benchmarks: *Forced Air Gas Heat & Electric A/C*
Cost Effective	10	9	9	1	1	1	1	1	9			4
Provide Monthly Cost Savings	7	1	9	1	1	1	1	1				1
Optional for new construction	9	9	1	1	1	3	1	9				5
Reliable	10	3					9	1	3			5
Long Lifetime	7	1	1	9	9		1	1	3			4
Year Round Comfort	5	1				9		1				4
Measurement Unit		$	yr.	yr.	yr.	BTU	#	%	#			
Target Value		<$13,000	<5 years	>20 years	>100 years	equiv to conv system	<Conventional	100	less than conv system	less than conv system		
Goal: Minimum(↓), Maximum(↑), Exact(-)		↓	↓	↑	↑	-	↓	↑	↓	↓		
Total		220	169	89	89	89	123	120	141	0	0	
Weighted		0.21	0.16	0.09	0.09	0.09	0.12	0.12	0.14	0.00	0	

Competitive benchmarks

5 = satisfies perfectly

4 = satisfies "mostly"

3 = satisfies "somewhat"

2 = satisfies "slightly"

1 = doesn't satisfy at all

Correlation

9 = Strong Relationship

3 = Medium Relationship

1 = Small Relationship

(blank) = Not Related

Figure 26: QFD to weigh out specifications

Technology Concepts		Concept 1	Concept 2	Concept 3
		Geothermal	Electric	Passive Solar
Criteria	Weight			
Cost Effectiveness	5	-	-	-
Monthly Cost Savings	5	+	0	+
Available for new construction	4	0	0	0
Reliable	4	+	+	0
Long Lifetime	3	+	+	+
Year Round Comfort	3	+	+	0
Reduction in Materials	4	0	0	+
+		15	10	12
0		8	13	11
-		5	5	5
Net Score		**10**	**5**	**7**

Table 7: Technology Concept Pugh Chart

Construction Concepts		Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
		New Housing	Retrofit	Single Home	Community	Standard Build	Custom Build
Criteria	Weight						
Cost Effectiveness	5	0	-	0	+	+	0
Monthly Cost Savings	5	0	0	0	0	0	0
Available for new construction	4	+	0	0	0	0	0
Reliable	4	0	0	0	0	0	0
Long Lifetime	3	0	0	0	0	0	-
Year Round Comfort	3	+	0	0	0	0	0
Reduction in Materials	4	+	0	0	+	+	0
+		11	0	0	9	9	0
0		17	23	28	19	19	25
-		0	5	0	0	0	3
Net Score		**11**	**-5**	**0**	**9**	**9**	**-3**

Table 8: Construction Pugh Chart

Payment Concepts		Concept 1	Concept 2	Concept 3
		Private Ownership	Robinhood Ownership	Third Party Ownership
Criteria	Weight			
Cost Effectiveness	5	-	+	+
Monthly Cost Savings	5	+	+	+
Available for new construction	4	+	+	+
Reliable	4	0	0	0
Long Lifetime	3	0	0	+
Year Round Comfort	3	0	0	0
Reduction in Materials	4	0	0	+
+		9	14	21
0		14	14	7
-		5	0	0
Net Score		**4**	**14**	**21**

Table 9: Payment Option Pugh Chart

Appendix 7. Estimate of Energy Usage for Community Geothermal Home

To get an estimate of the monthly energy usage for a home in a community geothermal neighborhood, we took actual electric bills from Doris's geothermal heated home (which has a separate meter for the geothermal system). We assumed that during the winter months the electric backup is running a lot due to the geothermal water not being warm enough during these months to fully heat the house, so we did not use these months in our estimate since the homes in the community geothermal neighborhood would not require an electric backup. We also assumed that in the summer months, the electric backup would not be running as much in Doris's home since the temperature of the geothermal water would be cool enough to cool the home. So in the summer, all that is happening is the circulation fan and recirculation pump are running. This would serve as a reasonable estimate of the electricity use in a home in a geothermal community with one exception – the home in the community would not have a circulation pump as the loop system is pressurized downstream in the pumping station. As a group, we agreed that a conservative estimate of the pump usage would be 40% of the total usage, so if we discount Doris's cooling amounts by 40%, we would approximate the usage of a home in the community geothermal neighborhood.

Beginning Date	End Date	Year	kWh
16-Oct	14-Nov	2012	958
14-Nov	17-Dec	2012	1262
17-Dec	17-Jan	2013	1660
17-Jan	19-Feb	2013	1994
19-Feb	19-Mar	2013	1484
19-Mar	17-Apr	2013	1283
17-Apr	16-May	2013	801
16-May	19-Jun	2013	699
19-Jun	18-Jul	2013	503
18-Jul	19-Aug	2013	633
19-Aug	17-Sep	2013	503
17-Sep	16-Oct	2013	537

Table 10: Utility bills of a home with a standard geothermal system.

Total kWh in the cooling months (April to October) = 3676 kWh

Average kWh in the cooling months = 612 kWh

Discounting the circulation pump = 367 kWh, so about 350 kWh per month

Appendix 8. Company Net Income Statement

Cost evaluation software was used to determine the five year impact for an engineering firm that operated under the pretenses of Community Geothermal Inc. This evaluation included taxes, payroll, administration expenses and capital expenditures. The overview for five years is shown below.

Cash Flow	2014	2015	2016	2017	2018
CASH RECEIPTS					
Income from Sales					
Cash Sales	$0	$0	$0	$0	$0
Collections	$0	$41,000	$205,000	$410,000	$341,667
Total Cash from Sales	**$0**	**$41,000**	**$205,000**	**$410,000**	**$341,667**
Income from Financing					
Interest Income	$6,553	$4,642	$3,456	$3,644	$3,279
Loan Proceeds	$0	$0	$0	$0	$0
Equity Capital Investments	$2,000,000	$0	$0	$0	$0
Total Cash from Financing	$2,006,553	$4,642	$3,456	$3,644	$3,279
Other Cash Receipts	$0	$0	$0	$0	$0
TOTAL CASH RECEIPTS	**$2,006,553**	**$45,642**	**$208,456**	**$413,644**	$413,644
CASH DISBURSEMENTS					
Inventory	$0	$0	$0	$0	$0
Operating Expenses	$817,866	$455,473	$335,672	$345,470	$355,703
Commissions/Returns & Allowances	$0	$0	$0	$0	$0
Capital Purchases	$50,000	$0	$0	$0	$0
Loan Payments	$0	$0	$0	$0	$0
Income Tax Payments	$0	$0	$0	$0	$0
Investor Dividend Payments	$0	$0	$0	$0	$0
Owner's Draw	$0	$0	$0	$0	$0
TOTAL CASH DISBURSEMENTS	**$867,866**	**$455,473**	**$335,672**	**$345,470**	$355,703
NET CASH FLOW	**$1,138,687**	**-$409,831**	**-$127,216**	**$68,174**	$68,174
Opening Cash Balance					$669,814
Cash Receipts					$344,946
Cash Disbursements					$355,703
ENDING CASH BALANCE	**$1,138,687**	**$728,857**	**$601,640**	**$669,814**	**$659,057**

Figure 27: Cash flow for first five years

Appendix 9. Utility Net Income Statement

Cost evaluation software was used to determine the five year impact for a utility that operated the community geothermal system. The overview for five years is shown below.

Cash Flow	2014	2015	2016	2017	2018
CASH RECEIPTS					
Income from Sales					
Cash Sales	$56,256	$56,256	$56,256	$56,256	$56,256
Collections	$0	$0	$0	$0	$0
Total Cash from Sales	**$56,256**	**$56,256**	**$56,256**	**$56,256**	**$56,256**
Income from Financing					
Interest Income	$151	$244	$344	$434	$554
Loan Proceeds	$350,000	$0	$0	$0	$0
Equity Capital Investments	$0	$0	$0	$0	$0
Total Cash from Financing	$350,151	$244	$344	$434	$554
Other Cash Receipts	$0	$0	$0	$0	$0
TOTAL CASH RECEIPTS	**$406,407**	**$56,500**	**$56,600**	**$56,690**	$56,810
CASH DISBURSEMENTS					
Inventory	$0	$0	$0	$0	$0
Operating Expenses	$10,356	$10,797	$11,166	$11,554	$11,963
Commissions/Returns & Allowances	$2,813	$2,813	$2,813	$2,813	$2,813
Capital Purchases	$330,000	$0	$0	$0	$0
Loan Payments	$24,358	$24,358	$24,358	$24,358	$24,358
Income Tax Payments	$0	$0	$0	$0	$0
Investor Dividend Payments	$0	$0	$0	$0	$0
Owner's Draw	$0	$0	$0	$0	$0
TOTAL CASH DISBURSEMENTS	**$367,527**	**$37,968**	**$38,337**	**$38,725**	$39,134
NET CASH FLOW	**$38,880**	**$18,532**	**$18,262**	**$17,965**	$17,676
Opening Cash Balance					$93,640
Cash Receipts					$56,810
Cash Disbursements					$39,134
ENDING CASH BALANCE	**$38,880**	**$57,412**	**$75,675**	**$93,640**	**$111,315**

Figure 28: Cash flow for first five years for community geothermal system