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Analysis of Cost and Energy Performance of Geothermal Heat Pump Systems in Southern Louisiana

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ANALYSIS OF COST AND ENERGY PERFORMANCE OF GEOTHERMAL
HEAT PUMP SYSTEMS IN SOUTHERN LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfilment of the
requirements for the degree of
Master of Science in Construction Management

in

The Bert S. Turner Department of Construction Management

by
Claudia de Lourdes Duran Tapia
B.S., University of New Orleans, 2015
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ABSTRACT

In the last three decades of geothermal heat pump (GHP) industry, there has been an urge to present data, especially performance and itemized installation cost, as a plan to reduce the lack of knowledge and trust towards GHP systems for heating and cooling. The potential of GHPs in hot and humid climates is significant [Tao and Zhu, 2012]. However, past research efforts have demonstrated this potential through the use of simulation rather than real-time data. Therefore, the scope of work for this research is to investigate GHP system applications for residential buildings in areas with hot and humid climates. Based on the scope of work, the objective for this research is to determine the cost, energy performance, and the payback period of GHP systems using real data collected from residences in southern Louisiana. To achieve this objective, the research answered the following questions: RQ1: How do geothermal heat pump systems perform in terms of energy usage and costs in hot and humid climates when compared to traditional HVAC systems? RQ2: What is the payback period for installing a GHP system in hot and humid climates for a residential dwelling?

A case study protocol was developed to collect building information, HVAC installation cost, financial incentive, energy usage, and end-user satisfaction data from residential buildings in Louisiana, three with GHP systems and two with conventional air-source systems. The electricity consumption and usage cost between the samples was compared using ANOVA in SPSS. This study concludes that tax credits can make GHP systems more affordable to average-size households as the payback period can be four times longer without the tax credits, and although the contractor base for GHPs in southern Louisiana is in its infancy, homeowners feel more satisfied with the performance of a GHP system than with the performance of a conventional air-source system.

CHAPTER 1: INTRODUCTION

1.2. Background

Energy is necessary for almost all facets of human existence: oil and gas for cooking and heating; electricity for cooling, lighting, appliances and machines; gasoline and diesel fuel for transportation; and a mix of energy supplies for a myriad other purposes [2008 APS Energy Report]. In terms of economics, energy is key to macroeconomic growth. In most cases, energy consumption increases as societies become more developed and their standard of living increases. The United States, for example, with the highest per capita gross domestic product reported by the World Bank, consumed 97.8 quads (1 quad= 10^{15} Btu) of energy in 2010 which represented 19% of all global consumption, making the US the second largest share after China [2011 Buildings Energy Data Book, p.1-7].

Americans spend 90% of their time indoors, working, living, shopping and entertaining in buildings that consume enormous amounts of energy. Since most of their energy comes directly or indirectly from fossil fuels, buildings are responsible for large quantities of greenhouse gas (GHG) emissions [2008 APS Energy Report]. According to the U.S. Energy Information Administration (EIA), in 2010 the building sector consumed 40% of total primary energy, but consumed 74% of all electricity usage.

Heating Ventilating and Air Conditioning (HVAC) systems are typically one of the largest components of building energy consumption, accounting for 42% of residential primary energy use and 32% of commercial building primary energy use [2011 Buildings Energy Data Book, tables 2.1.6 and 3.1.5]. Yet, a large fraction of the energy delivered to buildings is wasted because of inefficient building technologies and systems [2008 APS Energy Report]. In order to improve energy efficiency and savings, new technologies and systems must be explored,

particularly on the HVAC side of energy consumption. The U.S. Department of Energy Building Technologies Program (DOE-BTP) identified geothermal heat pumps as one such high-impact technology that can substantially reduce energy consumption and peak electrical demand in residential and commercial buildings.

Geothermal Heat Pumps (GHP), also known as Ground-Source Heat Pumps (GSHP) are among the most efficient, with annual energy consumption as little as half that of conventional systems. When compared to a typical Air-Source Heat Pump (ASHP) or typical furnace with a split-system air conditioner, the primary energy savings is in the range of 30% to 60%. In addition, for many commercial and residential applications, GHPs also provide water heating via a desuperheater [2012 DOE-BTP R&D Roadmap].

While GHPs are more energy efficient compared to the best available ASHPs and forced-air furnace systems, national impacts also depend on likely market penetrations of each alternative. Multiple studies identified three key barriers that inhibit GHP widespread industry growth 1) High first cost for ground loops, 2) Low market awareness and lack of knowledge/trust in GHP benefits, and 3) Infrastructure limitations including a limited number of qualified installers.

The purpose of this study is to address the second identified key barrier, especially in U.S. Southern states, by developing an economic feasibility analysis to compare the energy performance and cost of GHP systems with other conventional air-source HVAC systems installed in residential buildings in Southern Louisiana to determine the benefits and challenges of GHPs in climates that experience higher cooling loads than heating loads. This research employs utility and monitored data of actual GHP systems to calculate the payback period on the

investment of such systems. The study will compare the payback period obtained with and without considering the Federal residential tax credit.

To address the purpose of this research, this thesis is organized into six chapters and altogether describes the work that has been completed in order to achieve the objectives and answers the research questions for this research project. The following information briefly describes the contents of each chapter:

1.2. Report Organization

- Chapter 1, the current chapter, provides a background of building energy consumption and introduces GHPs as well as the benefits and barriers of GHPs in the United States market. This chapter also briefly explains the motivation that precedes this research, the purpose, and the main tasks.
- Chapter 2 presents a substantial collection of literature review, which contains the most important basic theory behind GHP systems. The content of this chapter is meant to expand the knowledge that homeowners or any person has in regards to non-conventional HVAC systems. This chapter attempts to clarify certain common misinterpretations of GHP system applications/limitations, particularly, applications based on geography and climate. Chapter 2 also highlights the difference between this study and previous similar research projects and how this difference intends to improve the body of knowledge.
- Chapter 3 describes the methodology used for this research. The third chapter provides the detailed steps for conducting this research from the initial literature review through the analysis and discussion of results and conclusions.
- Chapter 4 summarizes the general information of each case study and analyzes the information collected in each case study from surveys (Appendix A) and interviews.

Chapter 4 additionally presents the results of the statistical tests and payback period return on investment evaluation conducted based on the energy usage and cost data collected from each case study.

- Chapter 5 discusses the results obtained in the analyses presented in the previous chapter. The author utilizes this section to provide insight from the results observed in each case study, especially in cases where the system design was determined to be non-ideal for the facility, oversized, or unnecessarily complex. The discussion goes beyond numbers and presents information that highlights specific components of GHP systems in residential homes found in southern Louisiana as well as the perceived satisfaction in using a GHP system.
- Chapter 6 provides a brief summary of the knowledge gained from this study as well as reviewing the goals achieved and lessons learned in conducting this research project. This chapter presents the conclusions and limitations of this study, and suggests possible future research.

CHAPTER 2: LITERATURE REVIEW

2.1. Overview

Geothermal energy or geothermal heat is the thermal energy stored below the surface of Earth. Geothermal heat recovered from different depths below the surface provides unique and different possibilities of utilization. Among the advantages of geothermal energy is that the source does not depend on the weather and is available 24 hours per day and 7 days a week. Consumed geothermal energy is renewed and replenished from the internal planetary reservoir and is unlimited from a human perspective if used sustainably. Using renewable energy resources sustainably means that the rate of consumption is equal or smaller to the rate of renewing the process [Stober and Bucher, 2013].

Geothermal energy is used in three main ways: electricity generation, direct heating, and indirect heating and cooling via geothermal heat pumps (GHPs). These three processes use high, medium, and low temperature resources, respectively. High and medium temperature resources are usually the product of thermal flows produced by the molten core of the Earth, which collects in areas of water or rock. Low temperature resources are near ambient temperature and are mostly attributable to solar energy absorbed at the ground level and ambient air. High and medium temperature thermal resources are often deep within the earth, and the depth affects whether they can be exploited economically as drilling and other extraction costs can increase substantially when drilling at great depths [Self et al., 2012].

Low temperature geothermal resources are abundant and can be extracted and utilized in most locations around the world. Extracting such thermal energy is relatively simple because the depths involved are normally small. Heat pumps extract low temperature thermal energy and raise the temperature to that required for practical use [Self et al., 2012].

In terms of using geothermal energy, indirect heating and cooling using GHP technology is not the same technology as geothermal power generation, also known as enhanced geothermal systems (EGS), in which the extreme heat of subsurface geological processes is used to produce steam and ultimately to generate electricity. Nor is it the same as the direct use of geothermal heat, in which moderate-temperature geothermal sources such as hot springs are used directly to heat greenhouses, aquaculture ponds, and other agricultural facilities. GHP systems use the only renewable energy resource that (a) is available at most building's point of use, (b) is available on demand, (c) cannot normally be depleted (assuming proper design), and (d) are potentially affordable [Liu, 2010].

The biggest difference between GHP and conventional space conditioning and water heating systems is that, instead of rejecting heat from the buildings to the ambient air (in cooling mode) and extracting heat from fossil fuel combustion, electricity, or the ambient air (in space and/or water heating modes), a GHP rejects heat to or extracts heat from various ground resources, including the earth, surface water, recycled gray water, sewage treatment plant effluent, stormwater retention basins, harvested rainwater, and water from subsurface aquifers—either alone or in combination with conventional heat addition and rejection devices in a hybrid configuration [Liu, 2010].

GHPs are becoming more common as the costs of energy and equipment maintenance rise. When properly designed and installed, GHPs not only reduce energy use, but lower maintenance costs and extend equipment life since they have no exposed outdoor equipment. They are very simple devices and have only a slight difference from traditional heat pumps [Kavanaugh, 2006].

Finances of course are a key issue. Although GHPs need considerable initial investment (higher than common HVAC systems), in theory the overall performance is more favorable. The higher installation cost is due to the additional ground and site work (usually drilling and completion activities) and components (heat pump, connections, and distributors). On the other hand, running costs for GHPs are generally low, as usage is mainly electricity for operating the heat pumps and circulation pumps [Rybach, 2012].

Current GHP research and development efforts focus on reducing installation costs through advanced design and installation configurations and approaches. Additionally, many organizations, including the Department of Energy-Building Technologies Program (DOE-BTP), are focusing efforts on innovative financing approaches to defer or reduce upfront costs.

2.2. Geothermal Heat Pump System Components

A GHP system, in its most basic elements, consists of a ground loop, a heat pump, and a heating/cooling distribution system. This section will review the basic principles of the air-conditioner and the fundamentals of heat pumps, along with introducing the various types of ground loops and the different configurations available.

2.2.1. Indoor Components

2.2.1.1. Heat Pump

To understand how GHPs work we need to start from the basics: the air-conditioner. The air-conditioner, also known as the refrigeration cycle, consists of several primary components and four primary functions as shown in Figure 2.1.

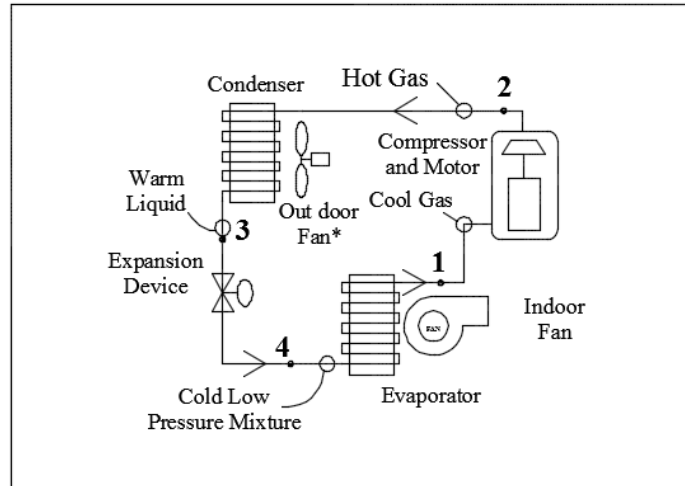


Figure 2.1. Simple Vapor-Compression Refrigeration Cycle (Adapted from: Kavanaugh, 2006)

The compressor (shown between points 1 and 2 in Figure 2.1), driven by an electric motor, is typically located outdoors, and “sucks” the refrigerant from point 4 through tubing in the evaporator coil. This action causes the liquid refrigerant to evaporate and become cold ($\approx 45^{\circ}\text{F}$). The evaporating refrigerant inside the tubes cools the air being circulated over the outside of the tubes and fins by the indoor fan. In order to move the refrigerant from point 1 to point 2, it must be raised to a higher pressure by the compressor.

The compressor causes the refrigerant to become a hot and high pressure vapor. The hot refrigerant vapor is sent through the tubing inside the condenser. Outdoor air circulated by a fan cools the refrigerant and causes it to return to a liquid (condense). Even though the outside air may be warm ($80\text{-}100^{\circ}\text{F}$) it is cooler than the hot refrigerant ($100\text{-}160^{\circ}\text{F}$). The warm liquid leaving the condenser at point 3 passes through an expansion valve device which lowers the refrigerant pressure before it returns to point 4 to repeat the cycle [Kavanaugh, 2006].

In water cooled or geothermal systems, a pump is used rather than an outdoor fan. Figure 2.2 shows the primary components of a water source air-conditioner followed by a description of the cooling-only cycle.

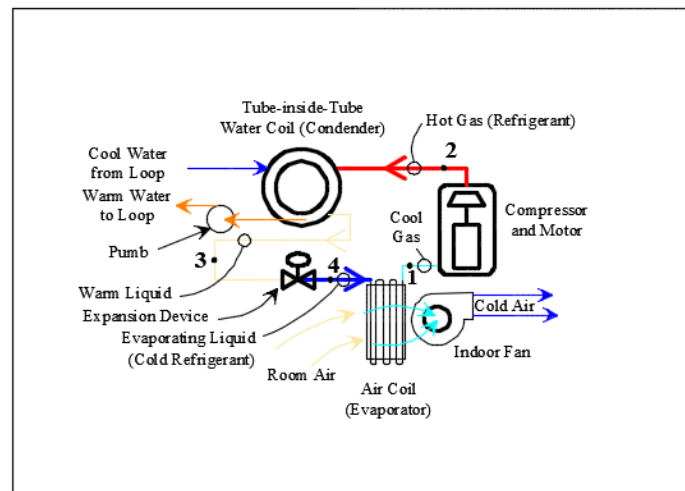


Figure 2.2. Water Source Air Conditioner (Adapted from: Kavanaugh, 2006)

The cycle of a water source-air conditioner in cooling-only mode is basically the same as the one described on the previous page except for the location of the compressor and the replacement of the outdoor fan with a pump. In this case, the compressor is located indoors and the use of a pump changes the process from points 2 to 3.

After the refrigerant is compressed, the hot and high pressure refrigerant vapor is sent through the outside tubing of a tube-inside-tube water coil condenser. Water is circulated by the pump through the condenser coil and outdoor water loop (ground loop, lake loop or water well) and cools the refrigerant causing it to return to a liquid (condense).

The water is typically 50°F to 90°F and is cooler than the hot refrigerant (90°F to 140°F). The liquid refrigerant leaving the condenser from point 3 passes through an expansion device which lowers the refrigerant pressure before it returns to point 4 to repeat cycle [Kavanaugh, 2006].

Heat naturally flows “downhill”, from higher to lower temperatures. A heat pump is a machine which causes the heat to flow in a direction opposite to its natural tendency or “uphill” in terms of temperature. Because work must be done to accomplish this, the name heat “pump” is used to describe the device. In reality, a heat pump is nothing more than a refrigeration unit.

Any refrigeration device (window air conditioner, refrigerator, freezer, etc.) moves heat from a space and discharges that heat at higher temperatures. One primary difference between a heat pump and a refrigeration unit is that heat pumps are reversible and can provide either heating or cooling to the space [Rafferty, 2001].

A heat pump is merely an air-conditioner with extra for-way reversing valve that allows the condenser (hot coil) and evaporator (cold coil) to reverse places in winter. Figure 2.3 and Figure 2.4 shows the reversing valve in heating mode and cooling mode respectively. The valve permits the refrigerant to travel from the indoor air coil to the compressor while in cooling mode and from the water coil to the compressor while in heating mode.

In heating mode, the reversing valve slides to a position that routes the hot refrigerant from the compressor through the top port to the indoor air coil (now the condenser) through the right bottom port of the reversing valve. Thus the air circulated by the indoor fan will be heated. After passing through the expansion device, the refrigerant enters the outdoor coil at a low temperature. Because the temperature of the refrigerant is low, heat can be transferred from the water to the refrigerant inside the evaporator [Kavanaugh, 2006].

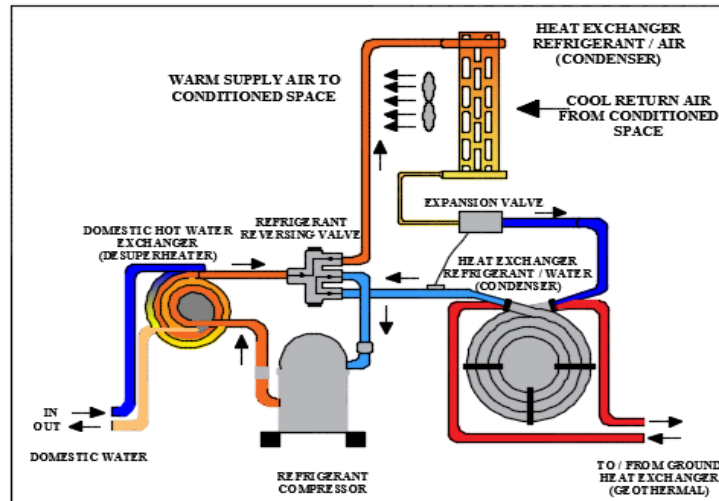


Figure 2.3. Heating Cycle (Adapted from: Oklahoma State University)

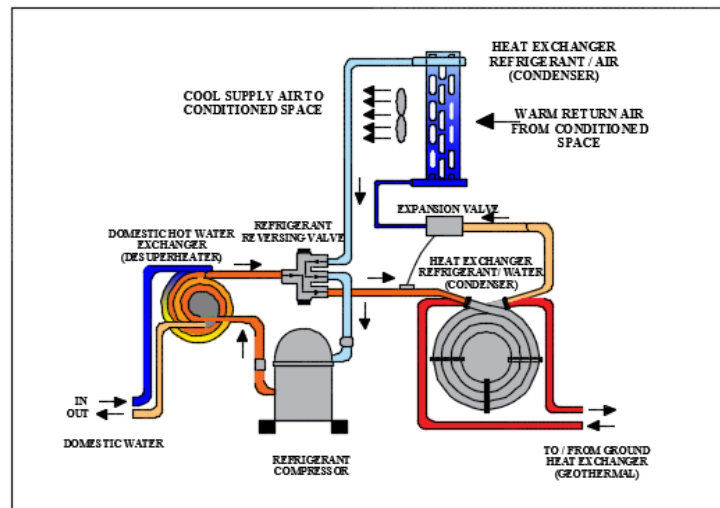


Figure 2.4. Cooling Cycle (Adapted from: Oklahoma State University)

The advantage of using water from the ground or lake/pond is that backup heat is often unnecessary. If the water loop is connected to a properly sized ground or lake coil loop, the heating efficiency is exceptionally high when compared to conventional systems. Figure 2.5 presents a more anatomically correct diagram of a “water-to-air” heat pump. Note that an additional heat recovery coil or desuperheater can also be added to the GHP unit to partially heat

domestic hot water (DHW) with waste heat in the summer and with excess heating capacity in the winter [Kavanaugh, 2006].

However, the heat pump only produces DHW when it is running for either space heating or cooling purposes. The percentage of annual DHW needs met depends upon the run time of the heat pump and DHW usage patterns in a facility. The largest savings occur in applications where the heat pump runs a large number of hours, particularly in cooling mode, and where alternative water heating is by electric resistance. The capacity of the desuperheater is directly related to the heat pump capacity. For an average family size (3.5 persons) with a 3-Ton heat pump, the annual savings on DHW would be in the range of 25% (colder climates) to 35% (warmer climates) or about \$100 - \$150 per year at \$0.08/KWh [Rafferty, 2001].

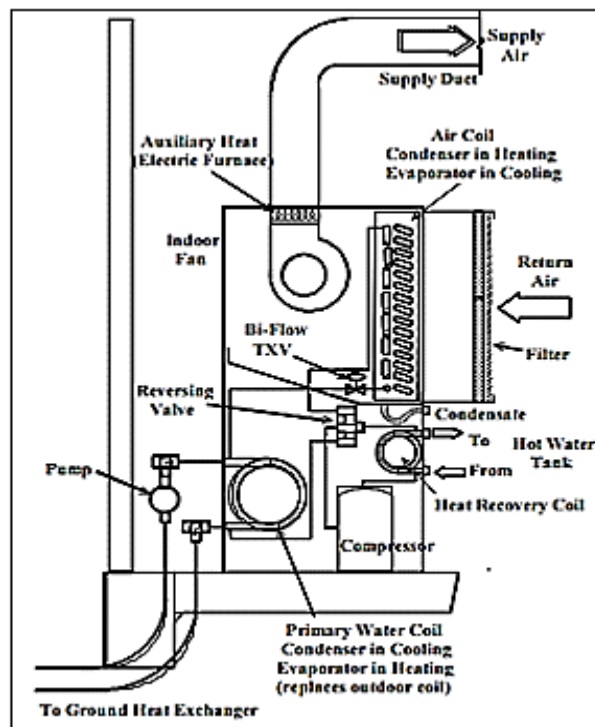


Figure 2.5. Ground-Source "Geothermal" Heat Pump Unit (Adapted from: Kavanaugh, 2006)

One of the most important characteristics of heat pumps, particularly in the context of home heating/cooling, is that the efficiency of the unit and the energy required to operate it are directly related to the temperatures between which it operates. In cooling, the inlet fluid temperature should be as low as possible to reduce heat pump energy consumption. While in heating mode the inlet fluid temperature should be as high as possible. In other words, the temperature lift across the heat pump which is the difference between the source and load temperatures should be minimized. This is important because it forms the basis for the efficiency advantage of GHPs over air-source heat pumps (ASHPs).

An ASHP must remove heat from cold outside air in the winter and deliver heat to hot outside air in the summer. In contrast, the GHP retrieves heat from relatively warm soil (or groundwater) in the winter and delivers heat to the same relatively cool soil (or groundwater) in the summer. As a result, GHP, regardless of the season is always pumping the heat over a shorter temperature distance than the ASHP. This leads to higher efficiency and lower energy use.

The most commonly used GHP unit is the single package water-to-air heat pump as shown in Figure 2.6. All of the components are contained in a single enclosure about the size of a small gas furnace. The single package design is a major advantage over the so-called split system used for ASHP. The lack of an outside unit reduces the amount of refrigerant required and the potential for leaks, which results in a major enhancement to reliability.

Virtually all GHP units use refrigerant R-22 which is considered a transition refrigerant with an ozone depletion value (ODP) of 0.05. High efficiency equipment generally contains a high efficiency compressor, larger air coil, higher efficiency fan motor, and sometimes, a larger refrigerant-to-water heat exchanger. Manufacturers also offer split systems, water-to-water heat

pumps, multi-speed compressors, dual compressor, and rooftop versions of this equipment to suit various applications [Rafferty, 2001].



Figure 2.6. Single Package Water-to-Air Heat Pump (Source: WaterFurnace)

2.2.1.2. Distribution System

The second indoor component of a geothermal system is the distribution system that is responsible for moving conditioned air from the heat pump throughout the home. The typical thermal output system in a residential application transfer heat to either a forced air heating/cooling system (a “water-to-air” system), or to a hydronic system for radiant heating, pool heating, or domestic water heating (a “water-to-water” system).

A typical residential system has a 3-ton (36,000 Btu/hr) thermal capacity. Depending on the layout of a given building and the nature of the heating/cooling loads, the building may use either a distributed architecture or a centralized architecture. A distributed architecture uses many small units, each one serving a specific zone or subset of the building space, while a centralized architecture uses fewer and higher capacity units in combination with a traditional distribution system [Goetzler *et al.*, 2012].

Whether it is a forced air or radiant system, an efficient HVAC distribution system is very important for a high performance geothermal system. For radiant systems, pipes must be properly sized, have proper spacing, and have a good thermal connection with the room. For air distribution systems, ducts must be tightly sealed and efficient [*Home Owner Guide to Geothermal Heat Pump Systems*, Ground Energy Support].

2.2.1.3. System Controls

The most basic type of control system is a heating and cooling thermostat. Programmable thermostats, also called setback thermostats, can be energy savers for homes by automatically adjusting the temperature setting when people are sleeping or not at home. Most of the common Wi-Fi thermostats (e.g. Ecobee®, Nest®) are compatible with geothermal heat pumps. The thermostat selected should be designed for the particular heating and cooling equipment it will be controlling, otherwise it could actually increase energy bills.

A thermostat should be located centrally within the house or zone on an interior wall. It should not receive direct sunlight or be near a heat-producing appliance. A good location is often 4 to 5 feet above the floor in an interior hallway near a return air grille. The interior wall should be well sealed at the top and bottom to prevent circulation of cool air in winter or hot air in summer [Louisiana Department of Natural Resources, 2010].

2.2.2. Outdoor Components

2.2.2.1. Ground Heat Exchanger

Unlike an ASHP with its outside coil and fan, a GHP also called Ground-Source Heat Pump (GSHP), relies on fluid-filled pipes buried beneath the earth as a source of heating in winter and cooling in summer. In heating mode, the GHP pulls heat from the earth and transfers

this heat to the indoor air or water, and in cooling mode the heat pump pulls heat from the indoor air and rejects the heat into the ground. This transfer of heat is called Geo-Exchange.

The primary undisturbed temperature of the ground heat source is given by the thermal properties (heat conductivity and heat capacity) and hydraulic properties (water and air content) of the subsurface. High porosity and void content of the ground typically reduce the heat conductivity. For example, if the groundwater table is low and the ground is in the vadose (unsaturated) zone instead of the saturated zone, the voids are filled with air instead of water which decreases the heat conductivity of the system [Stober and Bucher, 2013].

Therefore, it is important for engineers to perform a ground thermal conductivity test prior to starting the design of the ground heat exchanger (GHX). In general, steadily flowing groundwater can be expected to be beneficial to the thermal performance of closed-loop ground heat exchangers. The transfer of heat away from the borehole field via a fluid flow will alleviate the possible buildup of heat around the boreholes over time [Chiasson *et al.*, 2000].

The climatic conditions at a home's location also affect the temperature of the ground heat source. However, a few feet below the surface of the earth the ground remains at a relatively constant temperature all year round. Depending on the latitude of a location, ground temperatures can range from 45 F (7 °C) to 75 F (21 °C). Similar to a cave, the ground temperature is warmer than the air above it during the winter and cooler than the air in the summer [U.S. Department of Energy].

Eliminating the outside equipment means higher efficiency, less maintenance, greater equipment life, less noise, and stronger resilience [Gregor, 2012]. The buried piping in geothermal systems usually has a 25-year warranty. Most experts believe the piping will last longer, because it is made of durable plastic with heat-sealed connections, and the circulating

fluid typically has an anticorrosive additive. The actual costs of GHPs vary according to the difficulty of installing the ground loops as well as the size and features of the equipment. Proper installation of the geothermal loops is essential for high performance and the longevity of the system. Therefore, qualified and experienced geothermal heat pump contractors should be used for installation [Louisiana Department of Natural Resources, 2010].

2.2.2.2. Type of Ground Loop

Ground source heat pumps are generally classified by the type of ground loop. Selection of one over another type of ground loop depends mostly on the site characteristics, local regulations, and contractor availability.

Closed-loop heat pumps, also known as ground-coupled heat pumps (GCHPs), are the most common system type. Energy transfer in a GCHP involves four media: indoor air, the refrigerant gas, water in the loop, and the earth mass. Energy must pass through three heat exchangers: the indoor air-to-refrigerant coil, the refrigerant-to-water coil, and the water-to-earth pipe wall.

In the cooling mode, thermal energy flows from the indoor air to the refrigerant, to the loop water, and to the earth. Electric energy that powers the compressor enters the refrigerant gas as heat of compression and sensible heat from the motor and passes on to the earth. The total heat rejected to the earth is the sum of the heat absorbed from the indoor space plus the electrical energy needed to power the compressor.

In heating mode, the compressor heat energy goes into the indoor space along with the heat absorbed from the earth. For every unit of electrical energy needed to drive the heat pump compressor, three to four additional units of heat energy are absorbed from the earth [Braud, 1992]. The Ground heat exchanger (GHX) loop pipe material is typically high-density

polyethylene (HDPE). The heat pump controller operates the pumps to circulate the water/refrigerant solution throughout the GHX as necessary to meet the required heating or cooling load. In colder climates, water is usually mixed with refrigerant to prevent the water from freezing.

Closed-loop GHXs can have either a vertical, horizontal, or slinky-like configurations, which are laid in the ground or occasionally in a pond or lake. The vertical configuration consists of a loop that runs down the length of a vertical borehole and returns to the top. Each ton of capacity typically requires a single borehole of approximately 150 to 220 feet deep [Rafferty, 2008]. The vertical loop has a smaller ground surface area requirement, typically 200-400 ft² (5-10 m²/kW), which makes it more feasible for smaller properties but it adds on significant drilling costs to the total installation cost of the system [ASHRAE, 1995].

The major advantage of a vertical loop configuration is that it places the loop in a much more thermally stable zone as the deeper the boreholes, the ground temperature is more consistent. Thermal advantages of the vertical configuration over the horizontal configuration are less of a factor in moderate climates. The more extreme the climate, either in heating or cooling, the greater the advantage of the vertical system [Valizade, 2013].

Horizontal loops lie in trenches four to six feet deep and require 125 to 300 feet of trench per ton of cooling/heating capacity delivered [Rafferty, 2008]. This type of configuration usually represents a less expensive option since it involves less digging. On the other hand, it requires much more space and the ground temperature is more exposed to seasonal fluctuations. The length of pipe necessary is a function of system size, climate, soil/rock thermal characteristics and loop type. The ground surface area for a typical horizontal loop ranges from 2000 ft² to 3500 ft² per ton (50-90 m²/kW) [ASHRAE, 1995].

A variation of the horizontal loop is the spiral or “slinky” loop configuration in which the piping is laid out in an overlapping circular fashion. This configuration requires less ground area but more pipe length and pumping energy than a basic horizontal setup [Valizade, 2013]. Figure 2.7 shows the three different loop configurations, vertical, horizontal and slinky, within the same category of GCHPs.

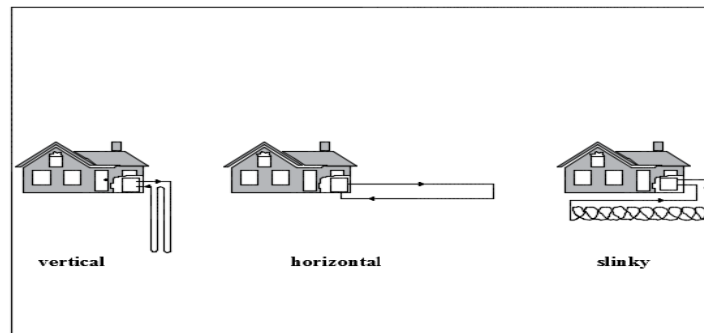


Figure 2.7. Closed-Loop or Ground-Coupled Heat Pumps (GCHP) (Adapted from: Kavanaugh and Rafferty, 1997)

Open-loop systems, also known as ground-water heat pumps (GWHP), pump ground water from a well into the heat pump’s heat exchanger and then re-inject the water back to the aquifer via a second well. In some applications, regulations allow the building owner to reject water into an existing body of surface water, thereby avoiding the need for an injection well. Surface disposal is the least expensive option; but, even if a disposal well is required, the capital cost is likely to be much less than the cost of a closed loop ground coupled heat pump system.

Water quality is also an important issue. Since the water is used directly in the heat pump, the issue of corrosion and/or scaling can be a problem. If the water is hard (>100 ppm of calcium carbonate) or contains hydrogen sulfide, a closed loop system would be a better choice. If the water is good quality and the house is to be served by a well for domestic water, serious consideration should be given to the open loop approach. Figure 2.8 shows the two

configurations for GWHPs, one as a two well and the other as a single well with surface disposal
[Goetzler *et al.*, 2012].

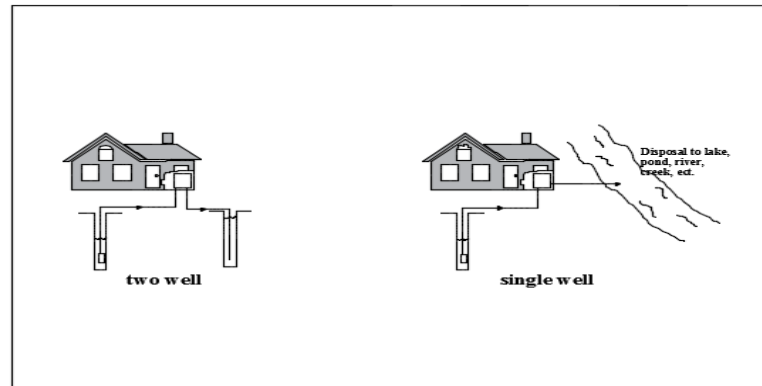


Figure 2.8. Open-Loop or Groundwater Heat Pumps (GWHP) (Adapted from: Kavanaugh and Rafferty, 1997)

Pond/lake configurations, also known as surface-water heat pumps (SWHP), can use either open-loop or closed-loop architectures. The latter often uses a submerged “slinky” configuration to exchange heat with the water at the bottom of a pond or lake [Goetzler *et al.*, 2012] as shown in Figure 2.9.

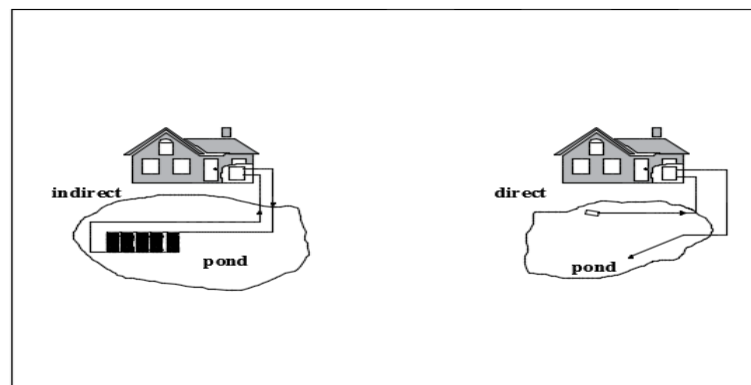


Figure 2.9. Lake/Pond or Surface Water Heat Pumps (SWHP) (Adapted from: Kavanaugh and Rafferty, 1997)

Direct Exchange (DX), also known as Direct GeoExchange (DGX) systems are a niche form of closed-loop system that circulate refrigerant from the heat pump directly through buried metal tubing instead of using a secondary glycol/water loop. Advanced DX systems are generally more efficient than systems that use a conventional ground loop. This efficiency gain is due to the lack of a water-circulation pump, which directly reduces electricity consumption, and the lack of a water-to-refrigerant heat exchanger, which decreases the temperature lift.

DX loops are also appealing due to lower installation costs. The ground loop itself is smaller and requires less land area. However, DX systems present many technical challenges for designers, installers and building owners. For example, underground leaks of refrigerant pose serious performance and environmental concerns, in addition to the high cost and complexity of locating and repairing such leaks [Goetzler *et al.*, 2012].

Estimates indicate that for offices and other similar building types, hybrid systems may provide benefits across the majority of climate regions. Hybrid configurations use a ground loop to meet the entirety of the smaller load in terms of heating and cooling load (most U.S. commercial applications are cooling-dominated). Figure 2.10 shows an example schematic of a hybrid system that utilizes a cooling tower to supplement the ground loop during the cooling season.

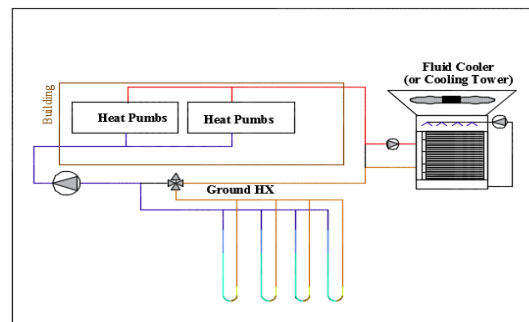


Figure 2.10. Schematic of Hybrid GHP (Adapted from: Goetzler et al., 2012)

Some large buildings now have systems that use a variety of alternative ground-heat-exchanger architectures, including flooded-mine water, municipal wastewater systems, standing column wells, and combinations of various water sources. Despite the need for custom engineering design for each system, utilizing such alternative heat sinks/sources enables greater energy savings and reduces overall costs [Goetzler *et al.*, 2012]. Table 2.1 summarizes the type of ground loops available for GHP systems.

Table 2.1. Summary of Type of Loop for GHXs

	Closed Loop/Ground-Coupled Heat Pump (GCHP)	Open Loop/Ground-Water Heat Pump (GWHP)	Pond Loop/Surface Water Heat Pump (SWHP)
Vertical	U-tube inside a vertical borehole of 150-220 ft. provide 1 ton of capacity.	Two well or single well with surface disposal. 1.5-2 gpm/ton required.	NA
Horizontal	Trenches buried 4-6 ft. deep. 125-300 ft. of trench provide 1 ton of capacity.	NA	NA
Slinky	Piping buried horizontally 4-6 ft. deep in an overlapping circular fashion.	NA	Submerged piping to exchange heat with water at the bottom of the pond. 300 ft. coil provide 1 ton of capacity.

* Hybrid systems can use any type of loop (usually supplement system with cooling tower)

2.2.3. Equipment Sizing

Typically, energy efficient homes require less demand for heating and cooling; so cost savings may be realized by installing units that are properly sized to meet the load requirements. Because energy bills in more efficient homes are typically lower, high efficiency systems may not provide as much annual savings on energy bills and may not be as cost effective as compared to less efficient houses.

It is important to size GHP systems properly as oversized equipment cost more to install, can waste energy and increase energy bills, and may decrease comfort such as providing inadequate dehumidification [Louisiana Department of Natural Resources, 2010]. Therefore, use a sizing procedure such as:

- Calculations in Manual J published by the Air Conditioning Contractors Association.
- Procedures developed by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE).
- Software procedures developed by electrical or gas utilities, the U.S. Department of Energy, HVAC equipment manufacturers, or private software companies.

The heating and cooling load calculations rely on the size and type of construction for each component of the building envelope, as well as the heat given off by the lights, people, and equipment inside the house. If a zoned heating and cooling system is used, the loads in each zone should be calculated separately.

Proper sizing also includes designing the cooling system to provide adequate dehumidification. In humid climate, such as the Southern United States, it is critical to calculate the latent load (the amount of dehumidification needed for the home). If the latent load is ignored, the home may become uncomfortable due to excess humidity. The Sensible Heating Fraction (SHF) designates the portion of the cooling load for reducing indoor temperatures (sensible cooling).

For example, in a HVAC unit with a 0.75 SHF, 75% of the energy expended by the unit goes towards cooling indoor air. The remaining 25% goes towards latent heat removal or taking moisture out of the air in the home. Many homes in places such as Louisiana have design SHFs of approximately 0.7, that is, 70% of the cooling will be sensible and 30% latent. Systems that

deliver less than 30% latent cooling may fail to provide adequate dehumidification in summer [Louisiana Department of Natural Resources, 2010]. Additionally, the size of the system will dictate the size of the Ground Heat Exchanger (GHX).

2.3. Standards and Certifications

2.3.1. Performance Ratings

All heat pumps are rated by the American Refrigerant Institute (ARI). For GHPs, results are published every six months in the Directory of Certified Applied Air Conditioning Products. Cooling performance is defined by the index EER which means Energy Efficiency Ratio. The EER is the cooling effect produced by the unit (in Btu/hr) divided by the electrical input (in Watts), which measures the number of Btu's removed by one Watt of electricity (Btu/Wh). Electrical input includes operating the compressor and fans, and a "pumping" allowance (for the groundwater or ground loop).

Heating performance is defined by the coefficient of performance (COP). COP is the heating affect produced by the unit (in Btu/hr) divided by the energy equivalent of the electrical input (in Btu/hr) resulting in a dimensionless value. COP also includes allowance for pumping. Both the COP and EER values for GHPs are valid only at the specific test conditions used in the rating.

COP and EER are single point values and therefore cannot be directly compared to seasonal values such as the seasonal energy efficiency ratio (SEER) or the heating seasonal performance factor (HSPF), which are published for air-source equipment. Table 2.2 summarizes typical installed costs for GSHPs and ASHP at typical and best efficiency levels [Rafferty, 2001].

Table 2.2. Typical and Best Efficiency Levels and Installation Cost of GSHP and ASHP (Source: Cooperman et al., 2012)

Technology	Cooling Efficiency	Heating Efficiency	Installed Cost
GSHP	Typical: 16 EER	Typical: 3.4 COP	\$ 3,000/ton
	Best: 30 EER	Best: 5.0 COP	\$ 5,250/ton
ASHP	Typical: 13 SEER	Typical: 7.7 HSPF	\$ 1,450/ton
	Best: 17 SEER	Best: 10.6 HSPF	\$ 2,300/ton

2.3.2. Heat Pump Efficiency Standards

There are a few industry standards that specify the minimum energy efficiencies of GSHP units in ground water and ground loop applications, including ASHRAE standards 90.1 (2010) and 189 (2010), as well as the Energy Star standards of the Environmental Protection Agency (EPA).

Heat pump efficiencies shall be measured in accordance with the ISO/AHRI/ASHRAE Standard 13256-1 (for water-to-air heat pumps) and 13256-2 (for water-to-water heat pumps). Federal and local governments adopt the minimum efficiencies specified in these standards in their related building energy efficiency codes, procurement requirements, and/or qualifications for financial incentives.

For example, the Energy Star certification is a prerequisite for obtaining the federal tax credits for GSHP installations. The Energy Star minimum efficiency requirements for GSHP equipment at various applications are listed in Table 2.3. Currently, more than 3,600 GSHP models have been certified by the ENERGY STAR® standard.

Table 2.3. ENERGY STAR Minimum Efficiency Requirements of GSHP Equipment (Source: www.energystar.gov)

Product Type	Configuration	EER	COP
Water-to-Air	Closed-loop	17.1	3.6
	Open-loop	21.1	4.1
Water-to-Water	Closed-loop	16.1	3.1
	Open-loop	20.1	3.5

2.3.3. System Design and Performance Evaluation Standards

The International Ground Source Heat Pump Association (IGSHPA), located at Oklahoma State University, originally developed and maintains a series of manuals and tools for the design and installation of GSHP or GHP systems that use closed-loop (horizontal or vertical) GHXs for residential and light commercial buildings.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has published several guides on the design, operation, and commissioning of commercial GHP systems. ASHRAE also maintains a chapter dedicated to the application of GHP technologies in its Handbook of HVAC Applications [ASHRAE, 2011].

The National Ground Water Association (NGWA) has published guidelines for the construction of vertical boreholes for closed-loop GHP systems, the scope of which includes loop field design, test holes and samples, borehole construction, piping, borehole grouting, loop field identification, and permanent loop piping decommissioning [NGWA, 2009]. These publications have been widely accepted by the United States GSHP industry.

Properly sizing the closed-loop GHX is very important as this component represents a significant share of the overall system cost. The sizing methodology needs to account for many factors, including the heat rejection and extraction loads, the physical layout of the GHX, the

thermal properties of soil/rock formation at the job site, and the thermal properties of the grouting material. Several software programs are used in the U.S. to size closed-loop vertical borehole GHXs, including GLHEPRO, GlheCal, EES, GLD, and GeoDesigner. These software programs require the user to provide building heating and cooling loads at design conditions and estimates of the cumulative loads.

In addition, these software programs cannot perform a comprehensive energy analysis of a whole building with a GHP system. There are a few integrated simulation tools, such as eQUEST, TRNSYS, and EnergyPLUS, that can be used in sizing the GHX and optimizing the design of GHP systems [Liu *et al.*, 2015].

2.3.4. Professional Certification Standards

Proper professional licenses or certifications are usually required in the U.S. to design and install GHP systems, especially for commercial projects. In all states, it is required that designers of GHP systems must be registered Professional Engineers, and in some states they must also be accredited by IGSHPA as Certified Geo Exchange Designers (CGD).

Many states require that ground loop installers be IGSHPA-accredited installers and/or drillers and that the installer of the indoor portion of the GHP system be an HVAC technician certified by the Air-Conditioning Contractors of America. Recently, the Geothermal Exchange Organization developed the first national certification standard for all the disciplines involved in GSHP projects [Liu *et al.*, 2015].

2.4. Geothermal Heat Pump Market Overview

2.4.1. Global Market Development

The growing awareness and popularity of GHPs has had a significant impact on the direct-use of geothermal energy. The installed capacity grew 1.51 times from 1995 through 2015 at a compound annual rate of 8.65%. This is due, in part, to better reporting and the ability of geothermal heat pumps to utilize groundwater or ground coupled sources anywhere in the world. Table 2.4 provides the five leading countries in terms of installed capacity in thermal megawatts (MWt) of heat pumps. The leading countries in terms of annual energy use in Terajoules per year (TJ/year) with heat pumps are: China, USA, Sweden, Finland, and Germany [Lund *et al.*, 2015].

Table 2.4. Worldwide Leaders in the Installation of GHPs (Source: Lund and Boyd, 2015)

MWt	TJ/year
USA (16,800)	China (100,311)
China (11,781)	USA (66,670)
Sweden (5,600)	Sweden (51,920)
Germany (2,590)	Finland (18,000)
France (2,010)	Canada (16,200)

Around US\$ 20 billion were reported as invested in geothermal energy by 49 countries during the period 2010-2014, for both direct use and power, doubled the amount from 2005 to 2009 for 46 countries. The average was US\$ 407 million per country, with countries investing over US\$ 500 million (or US\$ 100 million per year) being: Turkey, Kenya, China, Thailand, USA, Switzerland, New Zealand, Australia, Italy and South Korean (in descending order).

In terms of categories of investment: 28.3% was for electric power utilization in 16 countries, 21.8% was for direct-use in 32 countries, 25.6% was for field development including

production drilling and surface equipment in 32 countries, and 24.4% was for R&D including surface exploration and exploratory drilling in 48 countries [Lund *et al.*, 2015].

In regards to U.S. geographical distribution, GHPs are used in all 50 states and the District of Columbia. About 52% of domestic GHPs shipments went to ten states: Florida, Illinois, Indiana, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, and Texas. The split between the cumulative residential and commercial GHPs applications by 2012 is 3.5:1 [Navigant Consulting, 2013]. It is estimated that 75% of residential applications are in new construction and 25% in retrofits of existing homes [Ellis, 2008].

A recent Navigant Research report (2013) indicates that the United States represented 29% of global GHP installations by capacity with 13,564 MWt (3.9 million tons) installed in 2012. This corresponds to roughly 199 million m² (2.14 billion ft²) of building floor space [Liu *et al.*, 2016].

In the United States, there are 27 known domestic manufacturers of GHP equipment [US EIA, 2010]. Small packaged or split water-to-air heat pump units with cooling capacities ranging from 0.5 to 20 tons (1.74 – 70 kW) are most common in the United States. The efficiency and applicability of GHP units have been improved in recent years as a result of a number of technological advancements, including inverter-compressor technology with communicating controls, along with improvements and refinements to refrigerant coils and to all aspects of variable-speed motors [US EIA, 2010 and Liu *et al.*, 2015]

A report issued by Priority Metrics Group (2009) estimated that the GHP market in the United States was approximately \$3.7 billion in 2009, which includes the costs for design, equipment, and installation. A few surveys [Kavanaugh 1989, Huttner 1994, Kavanaugh *et al.* 1995, and Kavanaugh *et al.* 2012] have been conducted in the U.S. to collect cost information for

GHP systems. According to the study [Kavanaugh *et al.*, 2012], the average cost of a commercial GHP system increased by 129% from 1995 to 2012. This same study determined that the cost increase (177%) for the interior portion of the GHP system (including the heat pump and other major equipment, controls, piping, and ductwork) exceeded the cost increase for the closed-loop portion (52%) over the 17 year period.

The typical price, in 2006 dollars, of a GHP system installed in a new home is in the range of \$3000-5000 per ton; the average price for large-scale housing retrofits of GHP systems is \$4600 per ton [DOD, 2007]. The simple payback period for a GHP retrofit project in the United States is usually 8-14 years [DOD, 2007 and Liu, 2010]. For new construction, the payback period is shorter than retrofits, as a payback period of 5 years or more is common [Hughes, 2008].

The cost of a GHP system in the U.S. is about 2-3 times higher than similar GHP system in China. In China, the GHP industry has experienced explosive growth since 2005 due to strong promotion and financial incentives offered by the Chinese central government for renewable energy technologies such as GHPs. The cumulative building floor space conditioned by GHP systems in China grew from zero to 4.3 billion square feet in just one decade. The high growth rate may even increase in the future because of increased mandatory requirements and governmental investment in fighting the severe air pollution found in China [Liu *et al.*, 2015].

2.4.2. Status of U.S. GHP Industry

The U.S. GHP industry began to take shape in the early 1970s by general contracting and manufacturing entrepreneurs. The GHP industry includes manufacturers of water-source (geothermal) heat pumps, HDPE piping and fittings, circulating pumps, and specialty components, as well as the design infrastructure, an installation infrastructure, and various

electric utilities. Currently these infrastructures only exist in some localities, and elsewhere customers lack access to the technology [Hughes, 2008].

The small group of manufacturers presented in Table 2.5 is believed to produce most GHP units. Other major brands, such as Carrier, participate in the GHP market by sourcing water-source heat pump units from other manufacturers. The manufacturing base for HDPE pipe is large and well-established. Circulating pumps, propylene glycol antifreeze, plate heat exchangers, fluid coolers, and many other products used in GHP systems are already mass-produced to serve markets much larger than the GHP market [Liu, 2010].

Table 2.5. GHPs and HDPE Pipe Manufacturers

Geothermal Heat Pumps	HDPE Piping & Fittings
ClimateMaster (a unit of LSB Industries)	Performance Pipe (a unit of Chevron-Philips)
Florida Heat Pump (a unit of Bosch)	ISCO Industries
WaterFurnace International Inc.	Centennial Plastics
Trane (a unit of Ingersoll Rand)	
McQuay International (a unit of Daikin)	
Mammoth	
Carrier	

The economic impact of ground-coupled technology is truly unique. It is not sophisticated, high technology. It is good for local business. A new trade – ground loop contracting is needed to provide the ground-coupling. Bore drilling gives work to small water well drillers. Pipe installation, trenching, and other loop work use small contractors and local labor. The dollars the customer invests in ground-coupling feed the local economy instead of paying for a new large distant electric power plant [Braud, 1992].

Some regions of the country have their own regional geothermal professional organizations. Members of these organizations, presented in Table 2.6 are committed to furthering their industry.

Table 2.6. Regional Geothermal Professional Organizations

California	California Geothermal Heat Pump Association
Colorado	Colorado GeoEnergy and Heat Pump Association (CoGHPA)
Illinois	Geothermal Alliance of Illinois
Iowa	Iowa Geothermal Association
Connecticut	Connecticut Geothermal Association
New York	Long Island Geothermal Energy Organization (LIGEO)
Minnesota	Minnesota Geothermal Heat Pump Organization
New England	New England Geothermal Professional Association (NEPGA)
Wisconsin	Wisconsin Geothermal Association

As seen in the previous table, there is no regional geothermal professional organization representing southern states, even though from a scientific and technical point of view the potential for wide applications of GHP systems in hot and humid climate is significant [Tao and Zhu, 2012]. The IGSHPA provides access to their business directory of accredited installers, designers, and contractors. Table 2.7 summarizes the information found in the IGSHPA database for US southern states.

The number of accredited installers in the state of Louisiana is the second lowest after Mississippi, and in huge disadvantage compared to Texas. These results illustrate the lack of knowledge that HVAC contractors, as much as building owners, have in GHP systems and therefore the inevitable poor market competition within the HVAC industry in Louisiana.

Table 2.7. IGSHPA Business Directory for U.S. Southern States

State	Accredited Installer	Trainer	Certified GeoExchange Designer	Vertical Loop Installer	Certified Geothermal Inspector
AL	22	2	0	1	0
FL	16	2	4	0	1
GA	17	1	2	2	3
LA	6	0	1	2	0
MS	5	0	0	0	0
NC	58	3	3	8	3
SC	26	1	3	1	2
TX	90	8	8	8	1

In regards to academia, there is not much evidence of previous research work of GHPs in Louisiana, except by an independent study (1998) prepared for the U.S. Department of Energy by Oak Ridge National Laboratory. The study is about the installation of over 4,000 GHPs at the U.S. Army's Fort Polk military base in Leesville, LA; the world's largest installation of GHPs at the time (1996).

Smaller and less detailed case studies of GHPs in Louisiana can be found in research work of Braud (1992) and Smilie (1984). Harry J. Braud was a professor in the department of Agricultural Engineering at Louisiana State University, Baton Rouge. Most of his geothermal research publications are from the late 80s and early 90s. Nevertheless, the design of GHPs as well as the market barriers described in the study published by professor Braud has remained very much the same.

In the past decades research efforts regarding GHPs in Louisiana has decreased to almost zero. This might be one of the main reasons for the low awareness of the applications of GHPs in Louisiana, thus, for the low market penetration in this state. Hughes study (2008) surveyed GHP

industry experts and were asked to respond the question: What are the key barriers to rapid growth of the GHP industry? The most important identified barrier was the high first cost of GHPs to consumers and the given solution was to assemble independent, statistically valid, hard data on the costs and benefits of GHPs.

Given the need for data, a new sector in the GHP industry emerged. This relatively new sector is composed by companies that specialize in web-based GHP monitoring to track system performance. Ground Energy Support, for instance, developed a monitoring system called GxTrackerTM that monitors the basic operations of geothermal heating and cooling system and displays this real-time information online. The purpose of a monitoring system is to enable homeowners to insure that the heat pump system is providing the optimal return on investment.

2.4.3. Key Barriers

Initial cost and long payback periods clearly limit GHP system acceptance in many markets. Currently in commercial markets, GHPs are primarily limited to institutional customers (e.g., federal, state, and local governments and K-12 schools) that take the lifecycle view of a GHP system. In residential markets, GHPs are limited to a small subset of newly constructed homes that the builder plans to occupy and thus wants to equip with the best available system, and to home retrofits in which the owner plans to occupy the premises long enough to justify the investment [Liu, 2010].

While loop cost appears to be a major reason for higher first cost, the \$5,400 “indoor” equipment cost should be approximately the same as the \$4,000 typical first cost of a conventional system given the essentially equal complexity of the equipment and installation [Kavanaugh and Gilbreath, 1995]. Many new HVAC market entrants require additional resources and/or knowledge for safe and correct installation. Without knowledge of, and

experience with, of GHP systems and equipment, installers are hesitant to advertise and sell such systems. Furthermore, inexperienced designers tend to oversize GHP systems and/or add excessive backup capacity to provide a larger safety margin, but doing so unnecessarily increases their cost [Liu, 2010].

The lack of public awareness and trust in non-conventional HVAC systems directly leads to low motivation to invest in GHP systems. Given the large proportion of unmotivated consumers and inexperienced design and installation professionals, the GHP supply chain must educate consumers and even provide extra technical assistance for the design and installation of GHP systems. These extra selling and training costs are then included in the prices of GHP products [Liu, 2010].

Reductions in GHP system cost, improvements in installation quality, greater competition, and improved market penetration have occurred primarily in the areas that have been involved with GHPs for several years. The first cost of GHPs in areas that do not have established contractors and designers is often prohibitively high. These relatively high costs cannot be economically justified by many potential customers. Thus, the GHP industry in these areas does not develop sufficiently to support loop and HVAC contractors who will invest in the equipment and training necessary to install GHPs effectively [Kavanaugh and Gilbreath, 1995].

Consumers who make purchase decisions based primarily on first cost will not be likely candidates for purchase of higher cost equipment that can save them on operating costs. While part of this barrier can be overcome through greater consumer education and awareness of energy benefits, first-cost barriers must also be addressed directly [Goetzler *et al.*, 2014].

Recommendations are to concentrate on reducing the cost of the components with the greatest potential (heat pumps, indoor installation, and pumps) instead of overemphasize low-

cost loops at the expense of quality. GHP manufacturers have to find a way to reduce costs in order to become more competitive compared to high efficient air-source systems. Additional suggestions are to involve experienced contractors in loop research & development for affordable housing projects [Kavanaugh and Gilbreath, 1995].

2.4.4. Policies and Incentives

State and Federal government organizations typically use tax incentives, such as property and sales tax incentives, and tax credits to offset the costs of purchasing, installing, and/or owning a geothermal heating and cooling system. The residential renewable energy tax credit established by The Energy Policy Act of 2005, initially applied to solar-electric systems, solar water heating systems and fuel cells.

However, the Energy Improvement and Extension Act of 2008 extended the tax credit to small wind-energy systems and geothermal heat pumps, effective as of January 1, 2008. The credit was further enhanced in February 2009 by The American Recovery and Reinvestment Act of 2009, which removed the maximum amount for all eligible technologies (except fuel cells), placed in service after 2008 [DSIRE, 2017].

In 2015, the US federal government extended similar tax credits for commercial and residential solar energy installation, but for geothermal heat pumps and other clean energy technologies stopped at the end of December 2016. According to Doug Dougherty, President of the Geothermal Exchange Organization (GEO), geothermal heat pumps are 100% ‘Made in the USA’ with American-made components manufactured and installed by American workers. Without reinstatement and extension of federal tax credits, the entire geothermal supply chain, including manufacturers, distributors, dealers, contractors, installers, drillers – plus all the

families and small businesses that they support – will all see loss of investments and jobs [GeoExchange, 2017].

The geothermal industry is currently working towards the reinstitute and extension of commercial and residential installation tax credits geothermal heat pumps through 2021. Table 2.8 presents a few federal policies in place that apply to geothermal heating and cooling technologies (ground source heat pumps, direct-use). Additionally, the Database of State Incentives for Renewables and Efficiency (DSIRE) contains further information on state, local, utility, and federal incentives and policies that support renewable energy and energy efficiency,

Table 2.8. Current Federal Policies for Geothermal Technologies (Source: National Renewable Energy Laboratory, www.nrel.gov)

Current Policy	Description	Applicable Technology
Energy Policy Act of 2005 Residential Renewable Energy Tax Credit	30% residential renewable energy tax credit applies to ground source heat pumps. Effective January 1, 2008 – December 31, 2016.	Ground Source Heat Pump
Grants/Loans/Loan Guarantees	Geothermal projects can receive U.S. Department of Energy Tribal Energy Program grants and U.S. Department of Agriculture Rural Energy for America Program grants. Federal government has been authorized to provide loan guarantees for geothermal energy projects under Title XVII of Energy Policy Act of 2005.	Direct-use, Ground Source Heat Pump
Investment Tax Credit	10% investment tax credit for all expenditures on geothermal equipment except those required for transmission. No expiration date.	Direct-use, Ground Source Heat Pump

Table cont'd.

Current Policy	Description	Applicable Technology
Investment Tax Credit/Cash Grant Program	Section 1603 of Recovery Act allows taxable entities developing geothermal projects to take the 10% corporate investment tax credit as a cash grant.	Direct-use, Ground Source Heat Pump
Modified Accelerated Cost Recovery System	An IRS-implemented incentive that allows for accelerated depreciation on a 5-year tax schedule.	Direct-use, Ground Source Heat Pump
Recovery Act Research and Demonstration	Recovery Act provides \$350 million for geothermal research and demonstration. \$50 million available for ground source heat pump demonstration projects.	Direct-use, Ground Source Heat Pump

2.4.5. System Financing

High upfront costs continue to be a significant barrier to achieving potential monetary and energy savings from energy efficiency investments across the building sector. Over the past several decades, a number of innovative energy efficiency financing programs have emerged with the intent of reducing the upfront costs for energy efficiency improvements and assisting owners in the residential and commercial building sectors in achieving greater energy savings [ACEEE, 2011].

There are five major energy efficiency finance models prevalent today in the United States:

- 1) The energy savings performance contract (ESPC) model implemented by an energy service company (ESCO);
- 2) The energy services agreement (ESA) model;
- 3) The managed energy services agreement (MESA) model;
- 4) The property assessed clean energy (PACE) model; and
- 5) On-bill financing and on-bill repayment (OBF/OBR) approaches [WSGR, 2012].

While many energy efficiency finance options exist, these five models are among those attracting significant interest from both private-sector and public-sector stakeholders. Table 2.9 below summarizes the five emerging energy efficiency finance models.

Table 2.9. Energy Efficiency Finance Models (Source: WSGR, 2012)

Financing Model	Energy Savings Performance Contract (ESPC)	Energy Services Agreement (ESA)	Managed Energy Services Agreement (MESA)	Property Assessed Clean Energy (PACE)	On-Bill Financing/Repayment (OBF/OBR)
Market Penetration	High for MUSH; low for Commercial and Industrial	Low	Low	Low	Low
Target Market Segment	MUSH, Commercial, and Industrial	MUSH, Commercial, and Industrial	MUSH, Commercial, and Industrial	Residential, Commercial	Residential, Commercial, and Industrial
Typical Project Size	Unlimited	\$250,000 - \$10 million	\$250,000 - \$10 million	\$2,000 - \$2.5 million	\$5,000 - \$350,000
Allows for Extensive Retrofits	Yes	Yes	Yes	Yes	No
Repayment Method	Energy savings	Energy savings	Energy savings	Property assessments	Via utility bill
Security/Collateral	Depends on financing (e.g., lease or debt)	Equipment	Equipment	Assessment Lien	Equipment; Service termination
Responsibility for Utility Bills	ESCO or Customer	Customer	MESA provider	Customer	Customer

*Municipalities, Universities, Schools and Hospitals (MUSH) market

PACE and On-Bill Finance and Repayment (OBF/OBR) are the only models that target the residential segment. Very few ESCOs work in the residential market, and those that do target larger multi-family and public housing facilities.

Property Assessed Clean Energy (PACE) was developed in 2007 and is an innovative financing mechanism that enables low-cost, long-term funding for energy efficiency, renewable energy and water conservation projects, including geothermal.

Depending on local legislation, PACE can be used for commercial, nonprofit and residential properties. Interested property owners evaluate measures that achieve energy savings and receive 100% financing. PACE financing is repaid as an assessment on the property's regular tax bill for up to 20 years, and is processed the same way as other local public benefit assessments have been for decades. Figure 2.11 shows the basic structure of a PACE model.

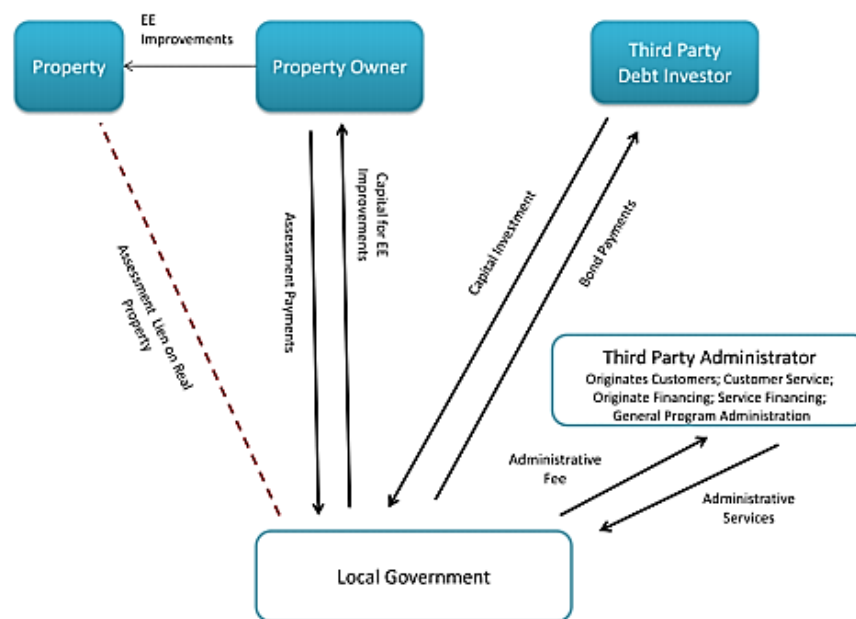


Figure 2.11. Basic PACE Structure (Source: WSGR, 2012)

Energy projects are permanently affixed to a property, meaning that the benefits and obligations can be transferred to a new owner upon sale. Moreover, the annual energy savings for a PACE project usually exceeds the annual assessment payment, so property owners are cash flow positive immediately [www.pacenation.us].

On-Bill Financing for Energy Improvements is another program that is starting to gain in popularity. In this program, electric utilities finance energy improvements and in much the same way as PACE, the cost is spread out over a period of up to 20 years, providing impressive net positive benefits.

2.5. Other Ground-Source Thermal Technology

Thermoactive piles, also known as energy piles, are foundation piles equipped with heat exchanger piping. The piles are installed in ground with poor load-bearing properties. The energy piles use the ground beneath buildings as heat source or sink, according to the season. Concrete has a good thermal conductivity and thermal storage capacity, which makes it an ideal medium as an energy absorber (heat exchanger).

To use these properties for energy foundations, high-density polyethylene plastic pipes of 20 or 25 mm diameter, with 2.0 or 2.3 mm wall thickness respectively, are installed within the concrete. They are placed to form several individual closed coils or loops, which circulate a heat carrier fluid (heat transfer medium) of either water, water with antifreeze (mainly glycol), or a saline solution. The plastic piping can be fixed to the reinforcement cages of the energy foundation in a plant or on the site.

There is no limitation to the depth of piles or diaphragm walls as far as the installation of energy absorber systems is concerned. The energy potential increases with depth: hence deeper foundations are advantageous. The economically minimum length of piles, barrettes or diaphragm wall panels is about 20 ft. [Brandl, 2006]. Khan *et al.* (2014) performed a study on energy foundation design in south Louisiana using the envelope features of a four-story building and LEED software.

2.6. Performance and Cost Data

The U.S. Department of Energy and the Environmental Protection Agency (EPA) are two federal government institutions that categorize geothermal or ground source heat pump systems as the most efficient, comfortable and environmentally friendly technology for space heating and cooling. Yet, one drawback is that the installation cost of a geothermal system is higher than that of an air-source system of similar heating and cooling capacity.

However, the additional costs are claimed to be returned in the form of energy savings within 5 to 10 years. American leaders in geothermal heat pump manufacturing state that along with a proper lifestyle and insulation, homeowners can reduce utility bills up to 70% resulting in a more attractive payback period of 2 to 3 years.

The residential renewable energy tax credit program for geothermal heat pumps expired on December 31, 2016. The reason for this decision is not publicly known. On the other hand, the lack of trust in GHP benefits by consumers, policymakers and regulators can be gradually overcome with the availability of costs and performance data of GHP systems using a representative sample of building applications.

[Tao and Zhu, 2012] used simulation program TRNSYS/EnergyPlus in their research paper, *Analysis of Energy, Environmental and Life Cycle Cost Reduction Potential of Ground Source Heat Pumps (GSHP) in Hot and Humid Climate*, to develop baseline building models and generate pre-retrofit data. Although simulation programs support data collection and analysis, assumed parameters not always coincide with reality. For example, the lighting, equipment schedule and weather data.

Other assumptions valid in simulation but that hardly occur in real life include, boreholes uniformly placed in the cylinder storage, perfectly constant temperatures (no saturation or heat

accumulation over periods of time), and overall neglects human error in every possible aspect of the installation. Steve Kavanaugh, Ph.D., Fellow ASHRAE, in his journal article *Long Term Performance of GHP Systems, Part 7: Achieving Quality* insists in the lack of information especially itemized cost details on recent HVAC system costs and service life.

This type of information is very important, and ASHRAE research efforts need to focus more on field surveys that collect performance and cost data for all types of HVAC systems [Kavanaugh, 2013]. Kavanaugh also suggests a framework for possible formats to be included in an “engineering portfolio”.

The idea of an engineering portfolio is to present a succinct listing of results to show how well primary goals have been achieved in previous geothermal projects. Some important information that should be shown in an engineering portfolio are building characteristics and energy conservation features, energy rating, mechanical system cost, and occupant satisfaction.

CHAPTER 3: METHODOLOGY

The content of this chapter describes the research methodology used to conduct this study on the installation and use of GHPs for residential facilities in southern Louisiana. The objective for this research is to determine the cost and energy performance, as well as the payback period return on investment of geothermal heat pump systems using real data collected from residences in southern Louisiana. To achieve this objective, the research will answer the following questions:

RQ1: How do geothermal heat pump systems perform in terms of energy usage and costs in hot and humid climates when compared to traditional HVAC systems?

RQ2: What is the payback period for installing a GHP system in hot and humid climates for a residential dwelling?

To address these questions and to achieve the objectives of this research, Figure 3.1 illustrates the research methodology, which is discussed in the sections below.

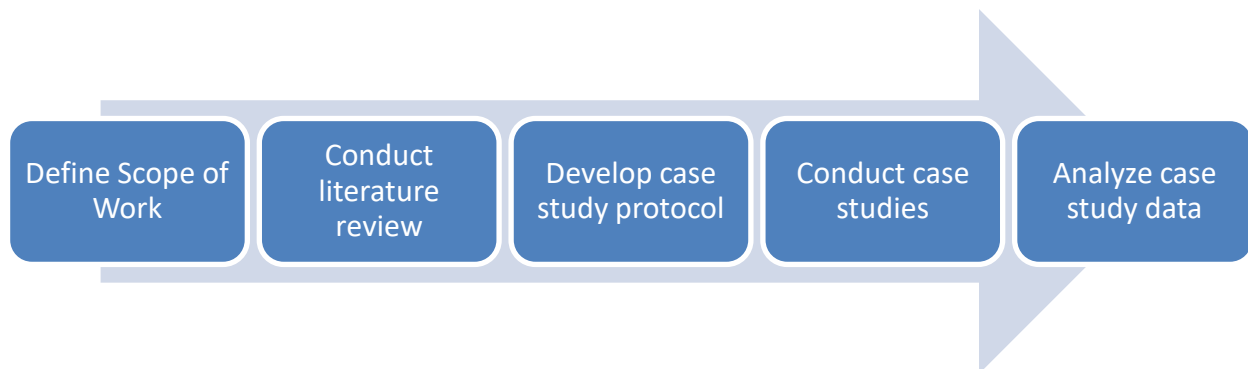


Figure 3.1. Research Methodology

3.1. Define Scope of Work

The focus of this research is to investigate GHP system applications in climates that experience high temperatures and high humidity, which includes the southern Louisiana area.

Based on a report in 2010 by the US. Energy Information Administration (EIA), GHP applications are more concentrated in areas with a cold climate and high population density. With fewer applications found in hot and humid climates, more research is needed in GHP systems used in these climate areas of the US. Further, this study investigated residential buildings rather than commercial buildings as GHP systems in southern Louisiana are difficult to find. The lack of GHP knowledge and contractor base limits GHP system applications more to residences than commercial facilities.

In terms of energy and cost performance of GHP systems, initial cost and energy usage and cost data was collected from residential homes found in New Orleans, Louisiana. Electricity energy usage and cost data was collected for 32 to 42 months from each case study residence via monitoring systems and monthly energy bills from utility companies. A lifecycle assessment of costs was not performed as the GHP systems investigated were installed in 2008 or later, meaning relatively little, if any, maintenance costs were collected from the case study residences. Also, federal incentives such as tax credits were included in the cost analysis. On the other hand, mortgages and other financing programs were not considered due to the variation in financing available to homeowners and difficulty to collect this type of information from homeowners.

3.2. Conduct Literature Review

To begin the research literature review, the author investigated the current status of energy consumption across the building sector, and found GHPs to be one of the emerging technologies with the potential to increase the efficiency of energy usage in residential buildings. The market development of GHPs was also investigated, especially in regions with hot and humid climates. From there, key barriers were identified and measured. Past research work that addressed key barriers such as lack of knowledge/trust towards GHPs were reviewed.

The author realized the benefits on collecting real, current data of cost and performance from installed GHPs, instead of been generated and extracted from computer simulations as in most research studies. Thus, examples of geothermal field surveys were searched and modified for Louisiana residential case studies. The majority of the literature review has been summarized in chapter 2 of this thesis.

3.3. Develop Case Study Protocol

A case study protocol was created and refined based on the intent of this research, using as reference the information from the literature review and the following two reports: *Survey and Analysis of Maintenance and Service Costs in Commercial Building Geothermal Systems* prepared by Caneta Research Inc. for the Geothermal Exchange Organization, and *Analysis of Energy, Environmental and Life Cycle Cost Reduction Potential of Ground Source Heat Pumps (GSHP) in Hot and Humid Climate*, prepared by [Tao and Zhu, 2012] from Florida International University for the U.S. Department of Energy.

The protocol, as shown in Appendix A, captures the actual conditions of the residence in question. The protocol provides a method to collect technical and non-technical data required for costs and benefits evaluation of GHP and conventional HVAC systems. Technical data will be employed in quantitative analysis to evaluate the energy savings compared to conventional air-source systems and to calculate the payback period to determine the return a homeowner can expect on their investment into a geothermal heat pump system. Non-technical data will be employed in a qualitative evaluation of end-user satisfaction and psychological barriers to considering and installing GHP systems in southern Louisiana.

3.4. Conduct Case Studies

The data collection process utilizes case studies of actual residential homes using geothermal heat pump systems for heating and cooling purposes found in southern Louisiana. The data collection includes identifying potential homes and homeowner participants, contacting potential participants, gathering geothermal system data from the homes with geothermal heat pump systems, gathering conventional HVAC system data from homes with similar characteristics as the geothermal heat pump system homes for comparison, and analyzing the consumption, cost, and satisfaction data collected from each case.

3.4.1. Identify Potential Participants

Sources that usually provide information on GHP system designers, installers and dealers are: ground source heat pump organizations (IGSHPA, GEOEXCHANGE, etc.), GHP manufacturers, HVAC contractors, and MEP engineering firms, Leadership in Energy and Environmental Design (LEED) projects and non-profit organizations involved in developing sustainable buildings. As this research was performed at Louisiana State University, LSU has an on-campus sustainable home laboratory called the LaHouse Home and Landscape Resource Center.

LaHouse is a resource center and a research-based showcase of home solutions that works closely with local mechanical contractors and other sectors involved in the construction of buildings. LaHouse includes a geothermal heat pump system for heating and cooling loads. Working with LaHouse staff, the researcher collected contact information for homes in southern Louisiana that have geothermal heat pump systems installed for heating and cooling.

In addition, the researcher explored non-profit home developers and builders that are or have been working in areas devastated by hurricane Katrina in New Orleans. Two non-profit

agencies in New Orleans have been developing sustainable homes, which include alternative energy sources such as geothermal and solar. Each non-profit organization was contacted and information was collected for potential homes with geothermal heat pump systems for use in this study.

3.4.2. Contact Potential Participants

Using the information from LaHouse and the two non-profit organizations, each of the homeowners were contacted via email that included a description of the project, the project goals and objectives, and potential outcomes and benefits. A reminder email was sent two weeks after initial contact if the researcher did not hear back from the potential participants. After receiving responses from the electronic invitation, teleconferences with the homeowners that accepted the participation request were scheduled in order to clarify breadth and width of the project, type of data needed, and roles and expectations on collaboration. After gaining approval from a homeowner, the researcher provided the case study protocol survey to the homeowner to be completed. A total of four homes with geothermal heat pump systems agreed to participate in this study.

3.4.3. Gather Geothermal System Data

The geothermal case study protocol survey prepared for this study is presented in Appendix A. The survey includes six sections:

- **Building information:** Includes the basic information of the residence such as location, type of residence, year constructed, floor area, number of floors, number of occupants, types of light bulbs and number of light bulbs, and type and number of appliances. This section also collected the specific details of the framing and insulation used for walls, roofs, and floors, as well as details on the windows of the structure.

- GHP system general information: Includes HVAC installation date, type of system, type of loop along with the details of the system such as header diameters and length of pipe installed.
- GHP system installation cost: A breakdown of the installation costs for the system. The costs were divided into two parts: ground loop costs and system costs. Each of the costs breakdowns includes the type of material, the quantity of material, cost of the material, and labor costs to install the materials.
- GHP system maintenance cost: Labor and material costs for scheduled and unscheduled maintenance of the geothermal HVAC system.
- Available metered data: The electricity usage data (kWh) and gas usage data (CCF) for each case. This information is used in the analysis of consumption, cost, and payback period.
- Occupant satisfaction: The overall perception of how satisfied homeowners were of their installed geothermal system in regards to cooling season comfort, heating season comfort, indoor air quality, acoustics, maintenance, and thermostat settings. Each question was ranked using a 5-point Likert scale that ranged from very satisfied (5) to very dissatisfied (1).

As part of the survey, the author offered a non-disclosure agreement which is committed to protect the participant's identity and information used in this study. In other words, all the responses were coded and kept confidential. Homeowners were encouraged to complete the survey with as much detail as possible. During the allotted time to complete the survey (two weeks) considerable follow up was necessary. Questions that remained empty such as itemized

installation costs, for instance, were answered with the assistance of the GHP system designer/installer.

Additionally, follow up in-person meetings took place to review the case study protocol survey and to collect any other needed information for this study. Participants in this project were met with once or twice for data validation but most importantly to acknowledge the motivation for installing GHPs in their homes. On-site visits supported additional information of the building and helped to obtain a better understanding of the operation and the settings of the GHP systems.

3.4.4. Gather Conventional HVAC System Data

Once the geothermal heat pump system homeowners agreed to participate, the researcher collected the building information using the case study protocol questionnaire. Then, the researcher identified similar homes with conventional HVAC systems and contacted these homeowners via email to see if they would participate in the study.

The case study protocol for conventional HVAC system homes, shown in Appendix B, includes the same six sections as the geothermal case study protocol questionnaire, except that the questions and cost data is in regards to the conventional HVAC system rather than a GHP system. In addition to the cost data provided by the homeowners, quotes were also requested to A/C contractors for reference. The quote sheet developed and distributed to HVAC contractors is provided in appendix C.

3.4.5. Comparison Requirements

In order to compare the actual consumption and cost of a residential geothermal heat pump system to a home with a conventional heat pump system, the researcher had to find homes

with conventional HVAC systems that have similar building envelope and characteristics to the GHP system homes in terms of the following aspects:

- Type of home
- Size of the home in square footage
- Location of the home
- Year constructed
- Number of floors
- Number of occupants
- Framing structure
- Insulation used

3.5. Analyze Case Study Data

The first step in the analysis is to determine if the collected data is statistically the same. To do this, an analysis of variance (ANOVA) was implemented. The analysis included the following steps and was conducted using the energy consumption data and the energy cost data for each case sample.

1. Determine the descriptive statistics for each sample (mean, standard deviation, variance, minimum, maximum, and range).
2. Test data for normality using MVP Stats statistical program.
3. Test for homogeneity of variance in SPSS using ADA (normal distribution) or ADM (non-normal distribution) values calculated in MVP Stats.
4. Test the mean values using a one-way ANOVA (established homogeneity of variance) or Welch ANOVA (lack of homogeneity of variance) in SPSS.

To obtain the energy cost, electricity and gas usage had to be converted to dollars. The electricity usage (kWh) was multiplied by the average retail price for electricity for Louisiana residential (cents/kWh) costs divided by 100 to obtain electricity cost in dollars. The retail price of electricity in Louisiana was obtained from the U.S. Energy Information Administration official website (www.eia.gov). The gas usage was multiplied.

Then, for each case study, the payback period was calculated by creating a table containing installation (materials and labor) costs along with the usage costs. The payback period, or “break even” point, in which the installation costs and usage costs for the GHP system equal the installation costs and usage costs for the conventional system, was calculated.

The payback period provides information on the return on investment period in terms of how long it will take for the initial investment in the GHP system to become more cost effective than a conventional system, taking into consideration the cost of installation and usage costs for the GHP system. Results of the statistical tests and payback period of each case study are presented in chapter 4.

3.6. Discussion and Conclusions

Case studies were discussed independently and cross-compared based on the results from the analysis and occupant satisfaction, and how the contractor base for GHPs in southern Louisiana affected the performance and cost of the GHP systems from the case studies. The discussion of results is found in chapter 5 with conclusions stated in chapter 6.

CHAPTER 4: ANALYSIS

This study collected technical and non-technical data from three homes with GHP systems in operation for 32 to 42 months (GH1, GH2, and GH3). GH2 was retrofitted with geothermal and the rest were new construction. A fourth home with a GHP system was surveyed (GH4). However, collecting specific information on the system as well as accurate cost data proved to be difficult due to the particular situation experienced in this home. Despite the fact that the information was incomplete and not validated, the author considered this particular case useful as an example for best practices to homeowners that consider investing in a GHP system in southern Louisiana.

Table 4.1 summarizes the basic building information and ground loop dimensions of the geothermal samples in the case studies. GH4 has no well or pipe information available. Then, Table 4.2 outlines the basic building information for the conventional HVAC system homes (CH1, CH2, and CH3). It is important to note that CH2 is the same home as GH2 since this sample was retrofitted with a geothermal heat pump system. Using the information collected from the survey shown in Appendix A, the sections below presents both samples (geothermal and conventional systems) included within each case study. The analysis conducted for each case study is presented, with discussions of the findings presented in chapter 5.

Table 4.1. General Information of the Residences with GHP Systems

Residence ID	Floor Area (ft²)	Type of Loop	Capacity (tons)	Ground Loop
GH1	1268	Closed Loop/Horizontal	3	954 ft.
GH2	3000	Closed Loop/Vertical	7	5 boreholes @250 ft.
GH3	1300	Closed Loop/Vertical	2	3 boreholes @250 ft.
GH4	1800	Closed Loop/Vertical	4	N/A ^a

Table 4.2. General Information of the Residences with Conventional HVAC Systems

Residence ID	Floor Area (ft²)	System	Capacity (tons)
CH1	1268	Air source heat pump	3
CH2	3000	Air conditioner with electric strip	7
CH3	1300	Air source heat pump	2

4.1. Case Study 1

The sections below describe the two sample homes, GH1 and CH1, included with case study 1.

4.1.1. General Information

GH1 is a single-family house on pile/pier foundation built in 2008 in New Orleans, LA. It is a two story, 3-bedroom residence with a conditioned floor area of 1,268 square ft. The building is designed for a total of four occupants and currently is being used as a model home and information center. The overall design of the building complies with a Platinum Certification Level according to the U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED). The home also has an energy rating certificate granted by Energy Star® that shows a Home Energy Rating System (HERS) Index of 13 or 87% better efficient home comparison.

The construction of GH1 as well as the installed technologies is meant to increase the energy efficiency. Among these technologies the most noticeable are the geothermal heat pump system, 5.3 kW solar electric photovoltaic system, green roof, rain water harvesting tank, and access to real-time information of utility data (water and electricity consumption) through a cloud-based building management platform. The owner of this building received federal incentives for the installation of energy efficient equipment.

CH1 is a single-family house on pile/pier foundation built in 2009 in New Orleans, LA. It is a two story, 3-bedroom building with a conditioned floor area of 1,120 square ft. The residence has a total of three occupants and it is also certified by Energy Star®. The home received the Energy Star certification in 2010, and it is rated with a HERS Index of 17 or 83% better efficient home comparison.

To achieve this energy efficiency, CH1 owns a couple of energy star appliances as well as an electric air source heat pump, 3.0kW solar electric photovoltaic system, and access to real-time information of utility data (water and electricity consumption) through a cloud-based building management platform. The owner of this building received federal incentives for the installation of energy efficient equipment.

The following paragraphs will describe the type of material and level of insulation of GH1 and CH1 shell components: interior wall, exterior wall, roof, floor, and windows. In addition to this, other features such as lights & appliance, mechanical (HVAC) system costs, electricity consumption and gas consumption will be reviewed in order to calculate the payback period or return on investment of the geothermal heat pump system installed in GH1.

4.1.2. Building Shell Features

The building shell information includes the framing structure for walls, roofs, and floors, the insulation for walls, roofs, and floors, and window information. The framing material and type of insulation were gathered from blueprints and construction document specifications. Table 4.3 presents the building shell for GH1 and Table 4.4 presents the building shell for CH1.

Table 4.3. Building Shell Features of GH1

Framing	Material	Type of insulation
Walls	Interior wall finish of 1 st and 2 nd story: ½ inch Dens-Armor plus gypsum board and ½ inch regular gypsum board, respectively. Exterior wall (advanced framing techniques): 2x6 wood studs, 7/16 inches OSB sheathing, draining housewrap, 2 inches rigid insulation, metal ties, 1x3 furring strips, trim boards, siding (Hardi-Panel), vented mesh, flashing.	2 inches Dow Thermax foil faced insulation. Above grade walls have an insulation level of R-13.
Roof	Upper and lower sloped roof: rafters, sheathing, roofing membrane, insulation, top roof sheathing, membrane, metal roof, solar mounting racks and solar panels. Flat roof: ceiling/roof joists, sheathing, roofing membrane, 4 inches rigid insulation, sheathing, roof drain piping, 2 ply Soprema SPS membrane roofing, roof drains, and parapets.	1 inch Dow Thermax and 3.5 inches soy-based spray foam. Vaulted ceiling and flat ceiling have an insulation level of R-27 and R-13, respectively.
Floor	Ground floor: joists, T&G PlyWood BlueWood treated floor decking, 2 inches rigid insulation, underfloor insulation protection, rim boards, joist ties, sills, and metal ties to sills.	2 inches Dow Thermax sheathing, 5/16 inches Hardi-Panel. Exposed floor has an insulation level of R-13.
Windows	Low-E, no vinyl, hurricane impact glass.	U-value=0.33 and SHGC=0.30

Table 4.4. Building Shell Features of CH1

Framing	Material	Type of insulation
Walls	Interior wall finish of 1 st and 2 nd story: ½ inch Dens-Armor plus gypsum board and ½ inch regular gypsum board, respectively. Exterior wall: 2x6 wood studs, 7/16 inches OSB sheathing, layer of moisture barrier, 2 inches foam board, 1x4 furring strips and siding.	Spray foam. Above grade walls have an insulation level of R-20.
Roof	Rafters, sheathing, roofing membrane, insulation membrane, and metal roof.	Spray foam. Ceiling has an insulation level of R-27.
Floor	Ground floor: joists, T&G PlyWood BlueWood treated floor decking, 2 inches rigid insulation, underfloor insulation protection, rim boards, joist ties, sills and metal ties to sill. Second floor: joists, subfloor, rim boards and joist ties.	Exposed floor has an insulation level of R-13.
Windows	Low-E, no vinyl, hurricane impact glass.	U-value=0.35 and SHGC=0.32

4.1.3. Lights & Appliance Features

According to GH1 homeowner the house has 29 lightbulbs. Additionally, their Energy Star® home energy rating certificate shows that the building has approximately 75 percent Fluorescent CFL and 25 percent Fluorescent Pin-Based lights. The energy certificate also describes the electricity consumption of the refrigerator in (kWh/yr) to be approximately 485; the dishwasher energy factor as 0.63; the fuel for the clothes dryer and range/oven is natural gas; and the ceiling fan (cmf/Watt) to be zero.

Per the CH1 homeowner, the house has 20 lightbulbs. Additionally, their Energy Star® home energy rating certificate shows that the building has approximately 70 percent Fluorescent CFL and 30 percent Fluorescent Pin-Based lights. The energy certificate also describes the electricity consumption of the refrigerator in (kWh/yr) to be approximately 388; the dishwasher energy factor as 0.46; the fuel for the clothes dryer and range/oven is natural gas; and the ceiling fan (cmf/Watt) to be zero.

To better understand a building's energy consumption, homeowners were also asked to list the quantity of appliances used in their residence. Table 4.5 outlines the type and number of appliances found in GH1 and CH1.

Table 4.5. Appliance Quantities of GH1 and CH1

Appliance	GH1 Quantity	CH1 Quantity
Water Heater	1	1
Refrigerator	1	1
Washing Machine	1	1
Clothes Dryer - Electric	0	0
Clothes Dryer - Gas	1	1
Dishwasher	1	1

Table cont'd.

Appliance	GH1 Quantity	CH1 Quantity
Sink Waste Disposal	0	0
Microwave	1	1
Toaster Oven	0	0
Ceiling / Portable Fans	5	1
TV	1	0
DVD/Blu-Ray Player	0	0
Desktop Computer	1	1
Laptop Computer	3	0
Printer/Scanner	2	1
Toaster	0	1
Electric kettle/pans	1	1
Range - Electric	0	1
Range - Gas	1	4
Coffee Machine	1	0
Blender	0	0
Iron	0	0
Hair Dryer	0	3
Vacuum Cleaner	1	0
Stereo	0	1
Clock Radio	0	0
Cable Box	0	0
Internet Router	1	1
Battery Chargers	4	5
Other:	HVAC control system	HVAC control system

4.1.4. Mechanical Features

GH1 uses a geothermal heat pump system to supply heating and cooling to the house. The installation of the HVAC system was finished in January, 2009. The geothermal heat pump system uses a closed-loop ground heat exchanger. Due to the proximity of the construction site to

a levee, there is a limitation in the depth of digging. Therefore, the geothermal pipes are buried horizontally in the backyard in a slinky loop configuration at a minimum of 4 feet below the ground surface as shown in Figure 4.1. The material of the pipes is PEX, which stands for Cross-linked Polyethylene, and the grouting material used for backfilling is bentonite. The spiral of the loop has a typical diameter of 4 ft. and the distance between the trenches is a minimum of 8 ft.

The diameter of the water loop pipe is $\frac{3}{4}$ inches and the diameter of the ground loop header is 1-1/4 inches. The total length of buried piping is approximately 954 ft. The horizontal PEX slinky coils are connected the rainwater harvesting storage tank as shown in Figure 4.2. Additionally, as a backup, the system has a cooling tower that runs an additional loop to keep the rainwater tank cool if needed.



Figure 4.1. GH1 Ground Loop Installation



Figure 4.2. Rainwater Harvesting Tank used in GH1

The geothermal heat pump unit manufacturer is WaterFurnace®. It is an N-5 Series water-to-air heat pump with a 3-ton capacity of heating and cooling. The model nomenclature NDV026A111CBL indicates that the equipment has a dual-stage compressor, vertical cabinet configuration, unit capacity of 026 MBTUH ($\approx 1,000$ BTU/hr), voltage of 208-230V, hot water generation, variable speed electronically commutated motor (ECM) blower, copper water coil, bottom (vertical) discharge air configuration, and left return air configuration.

According to the building plans and specifications package provided by owner, the heat pump unit compressor in cooling mode has 25,800 Total Btu/hr, 19,010 Sensible Btu/hr, and 19.3 EER. While in heating mode it has 27,040 Total Btu/hr and 4.1 COP. The system has also a desuperheater in line from the water heater. The geothermal system pre-heats the water as long as it is running, for this reason the building also has an instant water heater fueled by natural gas with an efficiency rating of 0.90.

The cooling tower is a SHINWA SBC-2ES vertical as shown in Figure 4.3. The fan motor is 115 Volt, 50 Watts, and the water flow is 6.0 gpm. The entering water temperature (EWT) is 90°F and the leaving water temperature is 80°F. The ambient wet bulb temperature is set as 95°F, and the operating weight is 80 lbs. The cooling tower pump is closed-coupled, direct driven, and is located under the deck. The pump operates at 115 Volt, 6.0 gpm, 20 head ft, 1750 rpm, and a minimum of 1/15 hp. A second pump is used for condenser water and is located in the mechanical room on the second story. It operates at 115 Volt, 6.0 gpm, 75 head ft, 1750 rpm, and a minimum of 1/4 hp.



Figure 4.3. Cooling Tower used in GH1

CH1 has uses an electric air-source heat pump that provides heating and three tons of cooling to the house. This particular heat pump is from Trane® U.S. Inc. the model number is 4TWX5024A1000AA (Volts 200/230, 60 Hz, O.D. Mot. 1/3 hp). The equipment is 8.5 HSPF and 15.3 SEER. The house also has an instant water heater (tankless) fueled with natural gas with an efficiency factor of 0.90. It also has a programmable thermostat for heating and cooling. The distribution system includes conventional ductwork for central distribution.

4.1.5 Material, Maintenance & Installation Costs

Most of the material, maintenance, and installation cost of the GHP system installed in GH1 were obtained from invoices provided by the owner. The installation and equipment cost of the air-source system in CH1 includes cost data as provided by the homeowner along with the average cost calculated from three quotes requested from three different A/C contractors located in New Orleans as reference and to supplement cost information missing from the homeowner. Tables 4.6, 4.7 and 4.8 outline the group loop costs, the HVAC system installation costs, and the maintenance costs, and the maintenance costs for GH1. Table 4.9 summarizes the cost of the air-source heat pump HVAC system found in CH1.

Table 4.6. Ground Loop Installation Cost for GH1

Ground Loop	Unit	Qty.	Equipment/Material	Labor	Total Cost
Drilling	ft		-----	2,737.50	2,737.50
Grouting	ft ³		120.00	280.00	400.00
Pipes & Fittings	ft	954		7,200.00	7,200.00
Exterior headers	ft		270.00	150.00	420.00
Total Ground Loop Installation Cost					\$ 10,757.50
Total Cost per ft. Trench					\$ 11.28

Table 4.7. HVAC Installation Cost for GH1

HVAC	Qty	Model	Equipment/Material	Labor	Total Cost
Heat pump	1	WaterFurnace NDV026	8,600.00	2,400.00	11,000.00
Water pump	1	Grundfos UP-26-99F	175.00	115.00	290.00
Controls		ONICON Inc.	1,880.36	400.00	2,280.36
Cooling tower	1	SHINWA SBC-2ES	400.00	716.00	1,116.00
Ductwork		-----	800.00	1,600.00	2,400.00
Interior piping		-----	200.00	500.00	700.00
Total HVAC Installation Cost					\$ 17,786.36
Total Project Cost					\$ 28,543.86

Table 4.8. Maintenance, Service & Repair Costs for GH1

Year	Cost (USD)	Description
2015	\$ 189.50	Checked system on arrival. Found that drain line was clogged up. Flushed out drain line and checked system. Charged system with one lb. of 410a refrigerant to get a better air split. Also checked electrical, amps, and Freon. System is running fine at this time
2014	\$ 90.00	Checked air conditioning system. Found it was down due to drain line clog. Flushed system. Operation OK

Table cont'd.

Year	Cost (USD)	Description
2013	\$ 315.00	Pumped down system took out old TXV valve, put in new one. Pressurized the system and out it under vacuum. Started the system up. Service Tech, TXV Kit Warranty, Nitrogen Usage
2012	\$ 256.00	Checked heat pump system. Found system was low on Freon. Leak checked system, found Freon was leaking through service valves and cap gaskets were worn out. Charged up system with 410a. Replaced caps and checked operation ok. Service tech, Freon, (2) valve caps
Total	\$ 850.50	

Table 4.9. HVAC Installation Cost for CH1

HVAC	Total Cost
Equipment (A/C unit)	4,145.50
Materials	1,284.00
Ductwork	1,770.50
Labor	3,689.50
Permits	65.00
Total HVAC Installation Cost	\$ 10,954.50

4.1.6. Consumption and Cost Data

The energy usage data collected for GH1 and CH1 included data from the system's monitoring and tracking system as well as monthly energy bills. The data includes 36 months of consumption (in kWh) and cost, from May 2014 through April 2017 for GH1 and 49 months of consumption and cost data, from August 2012 to October 2016 for CH1. Both GH1 and CH1 utilize electricity and gas for energy, and therefore electricity consumption and costs, and gas consumption and costs are presented in Table 4.10.

Table 4.10. Energy Consumption and Usage Cost for GH1 and CH1

Year	Month	Electricity Consumption (kWh)		Gas Consumption (CCF)		Electricity Usage Cost (USD)		Gas Usage Cost (USD)	
		GH1	CH1	GH1	CH1	GH1	CH1	GH1	CH1
2012	Aug		523		4		43.36		6.33
	Sep		345		4		29.53		5.89
	Oct		219		4		19.01		4.67
	Nov		142		7		11.91		6.99
	Dec		304		7		25.75		6.86
2013	Jan		319		6		28.33		5.49
	Feb		233		6		21.37		5.54
	Mar		252		7		23.16		6.55
	Apr		193		6		17.70		6.26
	May		300		6		29.10		7.57
	Jun		553		5		53.64		7.51
	Jul		536		5		52.42		8.15
	Aug		605		5		59.05		8.22
	Sep		557		4		54.14		6.28
	Oct		353		4		34.17		4.95
	Nov		305		8		28.03		8.03
	Dec		392		7		34.34		6.40
2014	Jan		510		8		43.71		7.41
	Feb		259		7		22.92		6.84
	Mar		288		8		26.67		8.56
	Apr		299		7		30.53		8.23
	May	123	378	1	5	12.71	39.05	1.36	6.80
	Jun	212	524	1	4	21.43	52.98	1.61	6.45
	Jul	218	546	1	5	22.19	55.58	1.72	8.62
	Aug	253	597	1	4	24.92	58.80	1.74	6.96
	Sep	317	509	1	4	31.13	49.98	1.63	6.51
	Oct	155	517	1	9	15.04	50.15	1.31	11.80
	Nov	152	430	1	11	13.54	38.31	1.02	11.21
	Dec	187	392	1	12	17.30	36.26	1.00	12.01
2015	Jan	231	454	1	11	20.61	40.50	0.95	10.45
	Feb	424	398	1	12	37.86	35.54	0.91	10.90
	Mar	328	432	1	12	29.29	38.58	0.93	11.14
	Apr	172	449	1	10	16.08	41.98	1.04	10.44
	May	168	534	1	9	16.46	52.33	1.27	11.46
	Jun	207	630	1	6	19.42	59.09	1.51	9.04
	Jul	302	640	1	2	28.27	59.90	1.63	3.26
	Aug	444	661	1	5	43.11	64.18	1.69	8.45
	Sep	407	573	1	7	39.56	55.70	1.64	11.48
	Oct	398	436	1	8	38.41	42.07	1.26	10.08

Table cont'd.

Year	Month	Electricity Consumption (kWh)		Gas Consumption (CCF)		Electricity Usage Cost (USD)		Gas Usage Cost (USD)	
		GH1	CH1	GH1	CH1	GH1	CH1	GH1	CH1
	Nov	163	302	0	8	14.91	27.63	0.00	8.02
	Dec	185	285	1	6	16.30	25.11	0.93	5.56
2016	Jan	241	438	1	11	20.49	37.23	0.83	9.15
	Feb	364	390	1	10	30.79	32.99	0.84	8.39
	Mar	247	362	2	10	22.55	33.05	1.84	9.19
	Apr	138	466	1	8	12.65	42.73	0.96	7.71
	May	167	448	1	5	15.50	41.57	1.16	5.80
	Jun	147	596	2	6	13.17	53.40	2.89	8.67
	Jul	355	642	2	5	32.16	58.17	3.31	8.29
	Aug	352	522	1	5	33.19	49.22	1.76	8.82
	Sep	383	639	1		36.46	60.83	1.68	
	Oct	352	487	1		32.84	45.43	1.37	
	Nov	194		1		17.77			
	Dec	155		1		14.14			
2017	Jan	226		1		17.42			
	Feb	231		1		17.81			
	Mar	144		1		11.10			
	Apr	161		1		12.41			

4.1.7. Comparison of Electricity Consumption and Usage Cost

The statistical analyses used for the collected consumption and cost data is the analysis of variance (ANOVA) test. Electricity consumption and gas consumption were collected from GH1 and CH1 and converted to electricity usage cost and gas usage cost using Tables shown in Appendix D and Appendix E. In conducting an appropriate ANOVA, three tests must be completed, which includes analyzing the shape of the data (test for normality), the spread of the data (test for homogeneity of variance), and the location of the data (ANOVA test of means). The sections below outline the results of the ANOVA for comparing GH1 to CH1.

4.1.7.1. Descriptive Statistics

Using SPSS, the descriptive statistics for the two cases in case study #1 is provided in Table 4.11 (energy consumption) and Table 4.12 (energy usage cost). In review of the

descriptive statistics, GH1 has a much lower average consumption and cost than CH1, which provides initial evidence that GH1 uses less energy and cost less to operate than CH1.

Table 4.11. Descriptive Statistics of Electricity Consumption in Case Study #1

HVAC System	Mean	Std. Deviation	Variance	Minimum	Maximum	Range	N
Geothermal (GH1)	283.85	96.52	9316.45	161.00	453.31	292.31	36
Conventional (CH1)	630.25	136.39	18602.28	336.47	812.62	476.15	49

Table 4.12. Descriptive Statistics of Electricity Usage Cost in Case Study #1

HVAC System	Mean	Std. Deviation	Variance	Minimum	Maximum	Range	N
Geothermal (GH1)	\$25.97	\$9.14	\$83.58	\$12.41	\$42.20	\$29.79	36
Conventional (CH1)	\$58.53	\$13.19	\$174.04	\$28.20	\$76.07	\$47.88	49

4.1.7.2. Test of Normality

The test for normality requires the review of the skewness and kurtosis of the data to determine if the data is normally distributed. Using the MVP Stats statistical program, the skewness and kurtosis values were calculated and presented in Table 4.13 and 4.14 below. Based on the results, the data for energy consumption is approximately normally distributed as the p-values are 0.05 or greater for skewness and kurtosis for GH1 and CH1. Then, for energy usage cost the p-values are less than 0.05 for three of the four tests, meaning that the energy usage data from GH1 and CH1 cannot be approximated by the normal distribution.

Table 4.13. Normality Test for Energy Consumption in Case Study #1

Case	Skewness	p-value	Kurtosis	p-value
GH1	0.438	0.250	-1.248	0.05 - 0.02
CH1	-0.549	0.104	-0.871	> 0.10

Table 4.14. Normality Test for Energy Usage Cost in Case Study #1

Case	Skewness	p-value	Kurtosis	p-value
GH1	0.918	0.011	0.437	0.096
CH1	0.926	0.004	0.522	0.014

4.1.7.3. Test for Homogeneity of Variance

Establishing normality means that the homogeneity of variance can be analyzed using Levene's Statistic for energy consumption based on the absolute deviation from the average values (ADAs), which were calculated in MVP Stats and transferred to SPSS to conduct the homogeneity of variance test. The results of the homogeneity of variance test for energy consumption is provided in Table 4.15. The results show non-significance at the 5% level, meaning that one can infer the variances are the statistically the same between GH1 and CH1.

Table 4.15. Test of Homogeneity of Variances for Electricity Consumption in Case Study #1

Levene's Statistic	p-value
2.562	0.113

With normality not established for the energy usage cost data, Levene's statistic can still be used, but the homogeneity of variance test needs to be run using the absolute deviation from the median values (ADMs). With the lack of normality and using ADM values, the results are more approximated than when normality is established and ADA values are used. Table 4.16 displays the results of the homogeneity of variance test for the energy usage cost data. The results show significance with a p-value less than 0.05. This means that one can infer that the variance values for GH1 and CH1 are not the same.

Table 4.16. Test of Homogeneity of Variances for Electricity Usage Cost in Case Study #1

Levene's Statistic	p-value
4.180	0.044

4.1.7.4. One-Way ANOVA of the Means

With normality and homogeneity of variance established for the energy consumption data, a one-way ANOVA can be performed using SPSS. The results of the ANOVA of the means for GH1 and CH1 are presented in Table 4.17. With the p-value less than 0.05, the results show that average energy consumption for GH1 is not equal to the average energy consumption of CH1. Therefore, the point estimate mean energy consumption value for GH1 is 283.85 kWh/month while the point estimate for CH1 is 630.25 kWh/month.

Table 4.17. Comparison of the Electricity Consumption means using ANOVA in Case Study #1

	F	p-value
Case Study 1 ANOVA	169.552	<0.05

For the lack of normality and unequal variances, the ANOVA of the means for the energy usage cost data can be conducted using Welch's statistic. Welch's statistic is a form of ANOVA that is robust to lack of homogeneity of variance by using an asymptotically distributed F-test. The results of the Welch ANOVA are presented in Table 4.18. The p-value is less than 0.05, meaning that the average energy usage costs are different between GH1 and CH1. The average monthly energy usage cost is \$25.97 for GH1 and \$58.53 for CH1.

Table 4.18. Robust Tests of Equality of Means for Electricity Usage Cost in Case Study #1

	Statistic	p-value
Case Study 1 Welch ANOVA	180.515	<0.05

4.1.8. Payback Period

Figure 4.4 illustrates the payback period for GH1 in comparison to CH1 for the cost of the geothermal system with and without applied federal tax credits. The payback period for GH1 is 32 years with the tax credit and 73 years without the tax credit. The extremely long payback periods for GH1 can be explained by the oversizing of the system and the multiple parties involved in the design and installation of the geothermal heat pump system, which contributed to the high cost of this system in comparison to the size of the home.

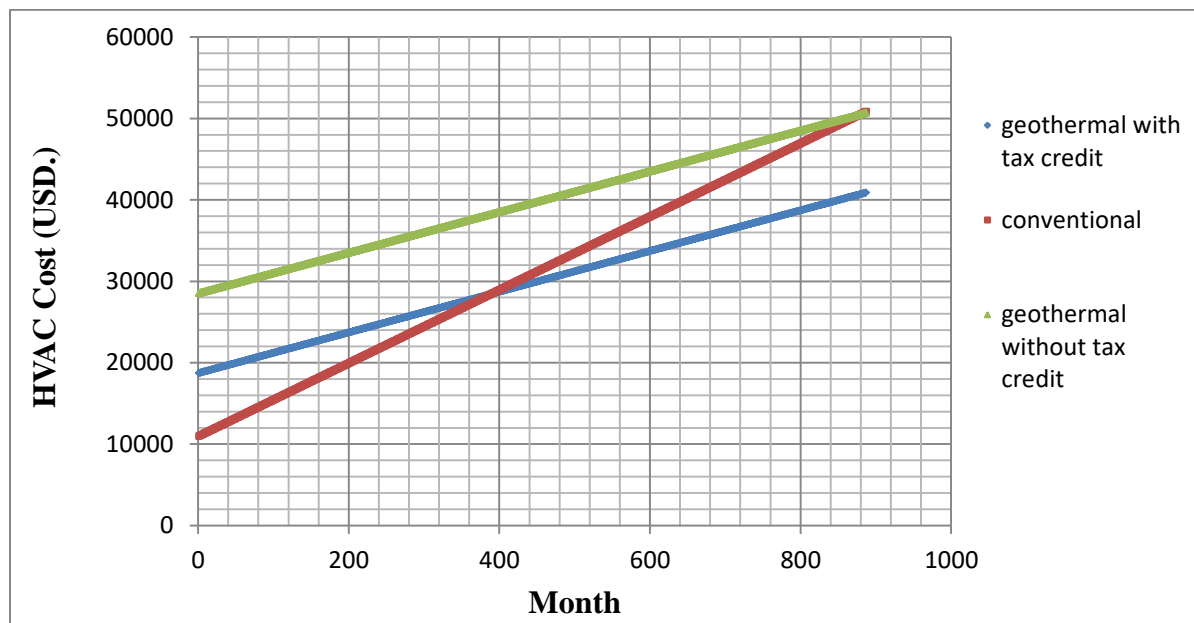


Figure 4.4. Payback Period of GH1 in Case Study #1

4.1.9. Occupant Satisfaction

The occupants for each case study answered six questions about the perception of their HVAC system. The questions asked how satisfied the homeowners are in terms of cooling comfort, heating comfort, indoor air quality, acoustics, maintenance, and thermostat settings. The results of the satisfaction questions are shown in Table 4.19.

Table 4.19. Occupant Satisfaction for GH1 and CH1

Aspect	GH1 Rating	CH1 Rating
Cooling Comfort	5/5	4/5
Heating Comfort	3/5	4/5
Indoor Air Quality	5/5	3/5
Acoustics	5/5	3/5
Maintenance Frequency and Response	4/5	4/5
Thermostat Settings	4/5	3/5

4.2. Case Study 2

This section details the information collected and analyses performed using the data from GH2. This particular case study is a retrofit installation of a geothermal heat pump system for a single-family home that, up until September 2014, utilized a conventional forced air HVAC system. Therefore, the data for comparison used included collecting consumption and usage cost data from prior to the installation of the GHP system and after the installation of the GHP system are the same except for the energy consumption and energy usage cost data. Therefore, the comparison home for GH2 is CH2, it is the same home but before the GHP system was installed.

4.2.1. General Information

GH2 is a single family residence built in 2000 and is located in New Orleans, LA. It is a two-story building with a floor area of 3,000 square ft. plus a guest house of 1,000 square ft. The residence has a total of two occupants. The building used a conventional air conditioning (CH2) system for 13 years. In October 2014 the system was replaced by a geothermal heat pump, but even before this retrofit happened, the homeowners also decided to improve some basic features of the house in order to increase the overall energy efficiency. Unlike the geothermal residence

in case study 1, GH2 is not LEED accredited. However, the homeowner still received federal tax credits for the installation of energy efficient equipment.

The following paragraphs will describe the type of material and level of insulation of GH2 and CH2 shell components: interior wall, exterior wall, roof, floor, and windows. In addition to this, other features such as lights & appliance, mechanical (HVAC) system costs, and electricity consumption will be reviewed in order to calculate the payback period of the geothermal heat pump system installed in GH2.

4.2.2. Building Shell Features

The building shell information includes the framing structure for walls, roofs, and floors, the insulation for walls, roofs, and floors, and window information. The framing material and type of insulation were gathered from blueprints and construction document specifications. Table 4.20 presents the building shell for GH2 and CH2.

Table 4.20. Building Shell Features of GH2 and CH2

Framing	Material	Type of insulation
Walls	Wood studs, brick, and cellulose	R-value=3.6 to 3.8/inch
Roof	Seal tab (architectural), insulated attic rafters	Foam insulation
Floor	1 st story has tile and 2 nd story has hardwood flooring	Foam board insulation
Windows	Low-E, vinyl double pane	

4.2.3. Lights & Appliance Features

GH2 and CH2 have four types of light bulbs; incandescent, halogen, CFLs, and LEDs. According to the homeowner, there are 120 light bulbs in the house and approximately 7 are Fluorescent tube bulbs. The house is completely electric, thus no gas usage. To better understand a building's energy consumption, the homeowner was also asked to list the quantity of

appliances used in the residence. Table 4.21 outlines the type and number of appliances found in GH2 and CH2.

Table 4.21. Appliance Quantities of GH2 and CH2

Appliance	Quantity	Appliance	Quantity
Water Heater	2	Iron	1
Refrigerator	2	Hair Dryer	1
Washing Machine	2	Vacuum Cleaner	1
Clothes Dryer - Electric	2	Ceiling / Portable Fans	2
Clothes Dryer - Gas	0	TV	4
Dishwasher	2	DVD/Blu-Ray Player	0
Sink Waste Disposal	1	Desktop Computer	1
Microwave	2	Laptop Computer	3
Toaster Oven	0	Printer/Scanner	1
Toaster	1	Stereo	0
Electric kettle/pans	0	Clock Radio	0
Range - Electric	1	Cable Box	2
Range - Gas	0	Internet Router	1
Coffee Machine	1	Battery Chargers	4
Blender	1	Other, Please list:	lighting control system

4.2.4. Mechanical Features

CH2 used a conventional air conditioning system until September 2014. The two story building had a York® 16 SEER air conditioner with electric heat strip and distribution system or ductwork. The conventional system provided 7 ton of heating and cooling to the 3000 square ft. house (3 ton upstairs and 4 ton downstairs). In October 2014 the conventional system was replaced by a geothermal heat pump (GH2) that uses a vertical closed-loop configuration. The

geothermal ground heat exchanger consists of five vertical boreholes of 250 ft. deep each. High density polyethylene (HDPE) U-tube runs through each borehole and the space between the U-tube and the ground is backfilled with bentonite. The diameter of the drilled borehole is 4- ½ inches and the diameter of the U-tube is 1 inch. On the other hand, the 1,000 square ft. guest house kept the 3 ton conventional unit up to the present date.

The geothermal heat pump unit manufacturer is WaterFurnace®. It is an N-5 Series water-to-air heat pump with a 4-ton capacity of heating and cooling. The model nomenclature NDVA049111 indicates that the equipment has a dual-stage compressor, vertical cabinet configuration, unit capacity of 049 MBTUH (≈ 1000 BTU/hr), voltage of 208-230V, hot water generation, and variable speed ECM blower.

According to the WaterFurnace heat pump specification package found in the water furnace website, the heat pump unit compressor in full capacity modulation for the 049 model has a flow rate of 12 gpm, a cooling capacity of 50800 Btu/hr and 19.3 EER. While in heating mode it has 38200 Btu/hr and 4.0 COP.

The model of the circulation/water pump used in the system is a Grundfos UP-26-116 and it has a capacity of 368 Watts. The building is also equipped with an intelligent thermostat (3 zones). The ductwork or HVAC distribution for the geothermal heat pump system is the same as the one used for the conventional system, only improved to avoid any duct leaks.

4.2.5. Material, Maintenance & Installation Costs

The material, maintenance, and installation cost of the GHP system installed in GH2 and CH2 were obtained from the owner and installer. The installation and equipment cost of the air-source system installed in CH2 includes cost data as provided by the homeowner along with the average cost calculated from three quotes requested from three different A/C contractors located

in New Orleans as reference and to supplement cost information missing from the homeowner. Tables 4.22 and 4.23 outline the ground loop costs, the geothermal HVAC system installation and maintenance costs for GH2, and Table 4.24 outlines the HVAC installation costs for CH2.

Table 4.22. Ground Loop Installation Cost for GH2

Ground Loop	Unit	Qty.	Equipment/Material	Labor	Total Cost
Drilling	ft	1,250	-----	7,500.00	7,500.00
Grouting	ft ³		215.00	335.00	550.00
Pipes & Fittings	ft				3,500.00
Exterior headers	ft				2,200.00
Total Ground Loop Installation Cost					\$ 13,750.00
Total Cost per ft. Trench					\$ 11.00

Table 4.23. HVAC Installation Cost for GH2

HVAC	Qty	Model	Equipment/Material	Labor	Total Cost
Heat pump	1	WaterFurnace NDV029	12,000.00	7,198.00	19,198.00
Water pump	1	Grundfos UP-26-116F	1,000.00	200.00	1,200.00
Controls		Thermostat intelligent	3,600.00	600.00	4,200.00
Ductwork		-----	1,100.00	1,700.00	2,800.00
Interior piping		-----	220.00	730.00	950.00
Total HVAC Installation Cost					\$ 28,348.00
Total Project Cost					\$ 42,098.00

*The only maintenance cost that the geothermal system has incurred is the \$70.00 for the filter that needs to be changed once a year.

Table 4.24. HVAC Installation Cost for CH2

HVAC	Total Cost
Equipment (A/C unit)	11,830.50
Materials	2,072.00
Ductwork	3,808.00
Labor	6,699.00
Permits	100.00
Total HVAC Installation Cost	\$ 24,509.50

4.2.6. Consumption and Cost Data

The energy usage data collected for GH2 and CH2 included data from the monthly energy bills. The data includes 42 months of consumption (in kWh) and cost, from July 2013 through December 2016. The GHP system was installed on October 2014. GH2 only utilizes electricity for energy. Therefore, electricity consumption and costs are presented in Table 4.25.

Table 4.25. Energy Consumption and Usage Cost for GH2 and CH2

Year	Month	Electricity Consumption (kWh)	Electricity Consumption (kWh)	Electricity Usage Cost (USD)	Electricity Usage Cost (USD)
		GH2	CH2	GH2	CH2
2013	Jul		3560		348.17
	Aug		4500		439.20
	Sep		4130		401.44
	Oct		4500		435.60
	Nov		4500		413.55
	Dec		3000		262.80
2014	Jan		4130		353.94
	Feb		3560		315.06
	Mar		3750		347.25
	Apr		2440		249.12
	May		2250		232.43
	Jun		2820		285.10
	Jul		3560		362.41
	Aug		4500		443.25
	Sep		4130		405.57

Table cont'd.

Year	Month	Electricity Consumption (kWh)	Electricity Consumption (kWh)	Electricity Usage Cost (USD)	Electricity Usage Cost (USD)
	Oct	1920		186.24	
	Nov	1920		186.24	
	Dec	1280		118.40	
2015	Jan	1760		156.99	
	Feb	1520		135.74	
	Mar	1600		142.88	
	Apr	1040		97.24	
	May	960		94.08	
	Jun	1200		112.56	
	Jul	1520		142.27	
	Aug	1920		186.43	
	Sep	1760		171.07	
	Oct	1280		123.52	
	Nov	960		87.84	
	Dec	960		84.58	
2016	Jan	1440		122.40	
	Feb	1520		128.59	
	Mar	960		87.65	
	Apr	960		88.03	
	May	1120		103.94	
	Jun	1520		136.19	
	Jul	2000		181.20	
	Aug	2320		218.78	
	Sep	2000		190.40	
	Oct	1280		119.42	
	Nov	1120		102.59	
	Dec	1840		167.81	

4.2.7. Comparison of Electricity Consumption and Cost

The statistical analyses used for the collected consumption and cost data is the analysis of variance (ANOVA) test. Electricity consumption was collected from GH2 and CH2 (same home) and converted to electricity usage cost using the table shown in Appendix D. In conducting an appropriate ANOVA, three tests must be completed, which includes analyzing the shape of the data (test for normality), the spread of the data (test for homogeneity of variance), and the

location of the data (ANOVA test of means). The sections below outline the results of the ANOVA for comparing GH2 before and after been retrofitted with geothermal.

4.2.7.1. Descriptive Statistics

Using SPSS, the descriptive statistics for case study #2 is provided in Table 4.26 (energy consumption) and Table 4.27 (energy usage cost). In review of the descriptive statistics, GH2 has a much lower average consumption and cost than CH2.

Table 4.26. Descriptive Statistics of the Electricity Consumption in Case Study #2

HVAC System	Mean	Std. Deviation	Variance	Minimum	Maximum	Range	N
Geothermal	1440.00	367.85	135314.29	960.00	1920.00	960.00	15
Conventional	3688.67	761.98	580612.38	2250.00	4500.00	2250.00	15

Table 4.27. Descriptive Statistics of the Electricity Usage Cost in Case Study #2

HVAC System	Mean	Std. Deviation	Variance	Minimum	Maximum	Range	N
Geothermal	135.02	35.18	1237.93	89.38	184.13	94.75	15
Conventional	350.52	71.25	5076.16	215.77	431.55	215.77	15

4.2.7.2. Test of Normality

The test for normality requires the review of the Anderson-Darling (A-D) goodness of fit test of the data to determine if the data is normally distributed. Using the MVP Stats statistical program, the A-D values were calculated and presented in Table 4.28 and 4.29 below. Based on the results, the data for energy consumption is approximately normally distributed as the p-values are 0.05 or greater for A-D values for geothermal and conventional. Then, for energy usage cost the p-values are greater than 0.05, which means that the energy usage data from case study #2 can be approximated by the normal distribution.

Table 4.28. Normality Test for Electricity Consumption in Case Study #2

HVAC System	A-D	p-value
geothermal	0.539	0.168
conventional	0.613	0.111

Table 4.29. Normality Test for Electricity Usage Cost in Case Study #2

HVAC System	A-D	p-value
geothermal	0.443	0.288
conventional	0.576	0.136

4.2.7.3. Test for Homogeneity of Variance

Establishing normality means that the homogeneity of variance can be analyzed using Levene's Statistic for energy consumption based on the absolute deviation from the average values (ADAs), which were calculated in MVP Stats and transferred to SPSS to conduct the homogeneity of variance test. The results of the homogeneity of variance test for energy consumption is provided in Table 4.30. The results show significance at the 5% level, meaning that one can infer the variances are statistically not the same in case study #2.

Table 4.30. Test of Homogeneity of Variances for Electricity Consumption in Case Study #2

Levene's Statistic	p-value
11.427	0.002

Table 4.31 displays the results of the homogeneity of variance test for the energy usage cost data. The results show significance with a p-value less than 0.05. This means that one can infer that the variance values for case study #2 are not the same.

Table 4.31. Test of Homogeneity of Variances for Electricity Usage Cost in Case Study #2

Levene's Statistic	p-value
6.355	0.018

4.2.7.4. One-Way ANOVA of the Means

With normality and homogeneity of variance established for the energy consumption data, a one-way ANOVA can be performed using SPSS. The results of the ANOVA of the means for case study #2 are presented in Table 4.32. With the p-value less than 0.05, the results show that average energy consumption for GH2 is not equal to the average energy consumption of CH2. Therefore, the point estimate mean energy consumption value for GH2 (geothermal) is 1440 kWh/month while the point estimate for CH2 (conventional) is 3688.67 kWh/month.

Table 4.32. Comparison of the Electricity Consumption means using ANOVA in Case Study #2

	F	p-value
Case Study 2 ANOVA	105.943	<0.05

The ANOVA of the means for the energy usage cost data can be conducted using Welch's statistic. Welch's statistic is a form of ANOVA that is robust to lack of homogeneity of variance by using an asymptotically distributed F-test. The results of the Welch ANOVA are presented in Table 4.33. The p-value is less than 0.05, meaning that the average energy usage costs are different in case study #2. The average monthly energy usage cost is \$135.02 for GH2 (geothermal) and \$350.52 for CH2 (conventional).

Table 4.33. Robust Tests of Equality of Means for Electricity Consumption in Case Study #2

	Statistic	p-value
Case Study 2 Welch ANOVA	110.323	<0.05

4.2.8. Payback Period

Figure 4.5 illustrates the payback period for GH2 (geothermal) in comparison to CH2 (conventional) for the cost of the geothermal system with and without applied federal tax credits. The payback period for GH2 is 2 years with the tax credit and 7 years without the tax credit. Therefore, case study #2 demonstrates that tax credits or incentives can make a difference and enable clean technologies, such as GHPs, to be affordable to the average household. Case study 2 also shows that geothermal heat pump systems can be retrofitted to existing homes and can perform well in hot and humid climates.

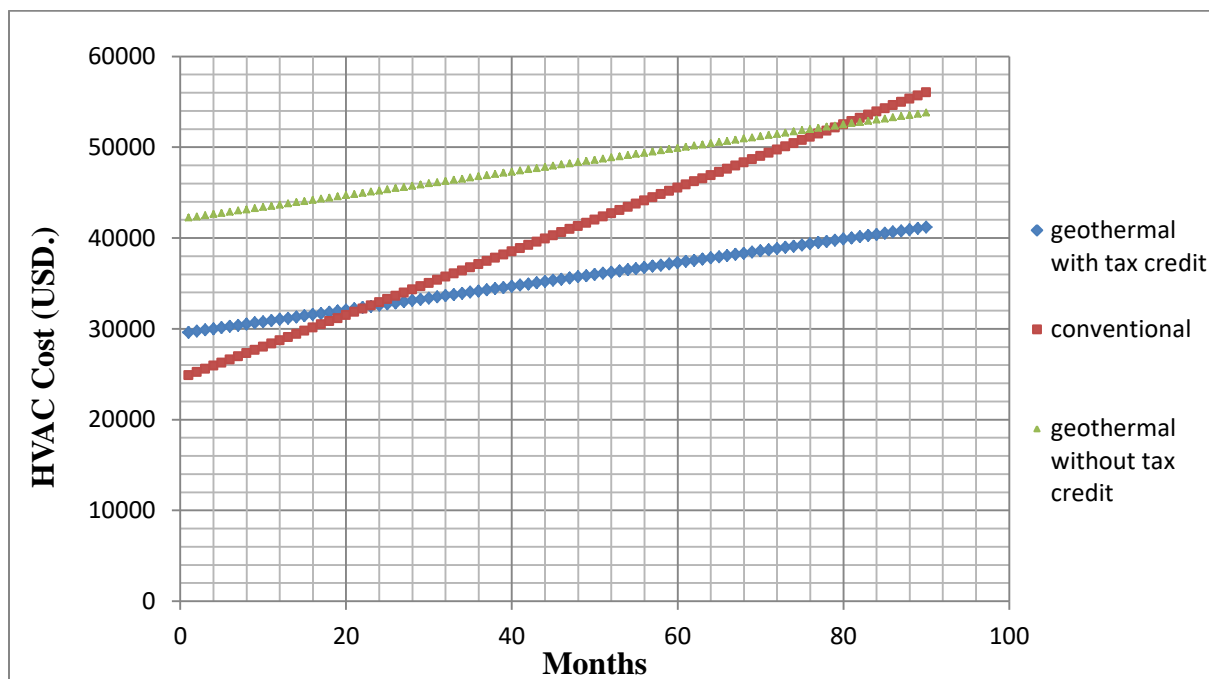


Figure 4.5. Payback Period of GH2 in Case Study #2

4.2.9. Occupant Satisfaction

The occupant answered six questions about the perception of the HVAC system before and after the geothermal retrofit. The questions asked how satisfied the homeowners are in terms

of cooling comfort, heating comfort, indoor air quality, acoustics, maintenance, and thermostat settings. The results of the satisfaction questions are shown in Table 4.34.

Table 4.34. Occupant Satisfaction for GH2 and CH2

Aspect	GH2 Rating	CH2 Rating
Cooling Comfort	5/5	4/5
Heating Comfort	5/5	4/5
Indoor Air Quality	5/5	4/5
Acoustics	5/5	3/5
Maintenance Frequency and Response	5/5	4/5
Thermostats Settings	5/5	3/5

4.3. Case Study 3

The sections below describe the two sample homes, GH3 and CH3, included with case study 3.

4.3.1. General Information

GH3 is a single family residence built in 2014 and is located in New Orleans, LA. It is a one story building with a floor area of 1,300 square ft. and a total of four occupants. Since its construction, the homeowners decided to install a geothermal heat pump system to heat and cool the house. CH3 is a single family residence built in 2010 and is located in New Orleans, LA. It is a one story building with a floor area of 1280 square ft. and a total of two occupants. The building has a conventional air-source system which uses a direct expansion condenser and an air handling unit.

The following paragraphs will describe the type of material and level of insulation of GH3 and CH3 shell components: interior wall, exterior wall, roof, floor, and windows. In addition to this, other features such as lights & appliance, mechanical (HVAC) system cost, and

electricity consumption will be reviewed in order to calculate the payback period of the geothermal heat pump system installed in GH3.

4.3.2. Building Shell Features

The building shell information includes the framing structure for walls, roofs, and floors, the insulation for walls, roofs, and floors, and window information. The framing material and type of insulation were gathered from blueprints and construction document specifications. Table 4.35 presents the building shell for GH3 and Table 4.36 presents the building shell for CH3.

Table 4.35. Building Shell Features of GH3

Framing	Material	Type of insulation
Walls	Conventional frame construction techniques	Open cell foam (R-value = 3.6/inch)
Roof	Wood rafters, asphalt shingles	Spray foam
Floor	Wooden floor	Closed cell foam (R-value = 6/inch)
Windows	Aluminum-double pane	

Table 4.36. Building Shell Features of CH3

Framing	Material	Type of insulation
Walls	2x4 stud framing, sheetrock	Batt (R-value = 2.9 to 3.8/inch)
Roof	Wood rafters, asphalt shingles	Spray foam
Floor	Wooden floor	Foam board
Windows	Low-E, vinyl double pane	

4.3.3. Lights & Appliance Features

GH3 has two types of light bulbs, incandescent and halogen. According to the homeowner there are 25 light bulbs in the house and approximately 3 are Fluorescent tube bulbs. This house is completely electric, thus no gas usage. The majority of CH3 light bulbs are

incandescent. According to the homeowner there are approximately 30 light bulbs. This house is completely electric, thus no gas usage. To better understand a building's energy consumption, homeowners were also asked to list the quantity of appliances used in their residence. Table 4.37 outlines the type and number of appliances found in GH3 and CH3.

Table 4.37. Appliance Quantities of GH3 and CH3

Appliance	GH3 Quantity	CH3 Quantity
Water Heater	1	1
Refrigerator	1	1
Washing Machine	1	1
Clothes Dryer - Electric	1	1
Clothes Dryer - Gas	0	0
Dishwasher	1	1
Sink Waste Disposal	1	1
Microwave	1	1
Toaster Oven	1	0
Ceiling / Portable Fans	1	6
TV	4	3
DVD/Blu-Ray Player	1	3
Desktop Computer	2	0
Laptop Computer	2	2
Printer/Scanner	1	1
Toaster	1	0
Electric kettle/pans	0	0
Range - Electric	1	1
Range - Gas	0	0
Coffee Machine	1	1
Blender	1	1
Iron	1	1

Table cont'd.

Appliance	GH3 Quantity	CH3 Quantity
Hair Dryer	1	1
Vacuum Cleaner	1	1
Stereo	1	1
Clock Radio	0	2
Cable Box	1	3
Internet Router	1	1
Battery Chargers	4	5
Other:	N/A	N/A

4.3.4. Mechanical Features

GH3 has a geothermal heat pump system to supply heating and cooling to the house. The system was installed in 2014, same year when the house was built. The geothermal heat pump system uses a closed-loop ground heat exchanger. The ground heat exchanger consists of three drilled vertical boreholes of 250 ft. deep each or 750 ft. in total. High density polyethylene (HDPE) U-tube runs through each borehole and the space between the U-tube and the ground is backfilled with bentonite-cement. The diameter of the drilled borehole is 4 inches and the diameter of the U-tube is 1 inch. The diameter of the ground loop header is 1-1/4 inches and the material is HDPE.

The geothermal heat pump unit manufacturer is WaterFurnace. It is a 3 Series 300A11 water-to-air heat pump with 2 ton capacity of heating and cooling. The model nomenclature LDV024-115 indicates that the equipment has a dual-stage compressor, vertical cabinet configuration, unit capacity of 024 MBTUH (≈ 1000 BTU/hr), voltage of 208-230V, hot water generation, and 5 Speed ECM blower.

According to the WaterFurnace heat pump specification package found in the water furnace website, the heat pump unit compressor in full capacity modulation for the 024 model

has a flow rate of 8 gpm, a cooling capacity of 23100 Btu/hr and 15.6 EER. While in heating mode it has 18900 Btu/hr and 3.8 COP. The model of the circulation/water pump used in the system is a Grundfos UP-26-99 and it has a capacity of 205 Watts. The ductwork or central HVAC distribution for the geothermal heat pump system is the same as used for conventional systems, only improved to avoid any duct leaks.

CH3 has a Goodman GSZ14-0241AA energy-efficiency split system air-source heat pump. The unit type is a heat pump that uses R-410A as refrigerant. The heat pump is matched with an air handling unit that circulates the conditioned air throughout the home. The unit condenser has a fan motor of 1/6 hp, nominal capacity of 2 tons and an efficiency of 14 SEER. The electrical data for the heat pump shows 208/230 V, 1 Phase, 60 Hz. The cooling capacity and heating capacity of the unit are both 24000 Btu/h.

4.3.5. Material, Maintenance & Installation Costs

The material, maintenance, and installation cost of the GHP system installed in GH3 were obtained from the owner and installer. The installation and equipment cost of the air-source system in CH3 includes cost data as provided by the homeowner along with the average cost calculated from three quotes requested from three different A/C contractors located in New Orleans as reference and to supplement cost information missing from the homeowner.

Tables 4.38 and 4.39 outline the group loop costs, the HVAC system installation costs, and the maintenance costs for GH3. Table 4.40 summarizes the cost of the air-source heat pump HVAC system found in CH3.

Table 4.38. Ground Loop Installation Cost for GH3

Ground Loop	Unit	Qty.	Equipment/ Material	Labor	Total Cost
Drilling	ft	750	-----	4,500.00	4,500.00
Grouting	ft ³		120.00	200.00	320.00
Pipes & Fittings	ft		140.00	150.00	290.00
Exterior headers	ft		120.00	150.00	270.00
Total Ground Loop Installation Cost					\$ 5,380.00
Total Cost per Bore foot					\$ 7.17

Table 4.39. HVAC Installation Cost for GH3

HVAC	Qty	Model	Equipment/Material	Labor	Total Cost
Heat pump	1	WaterFurnace LDV024	5,258.00	2,500.00	7,758.00
Water pump	1	Grundfos UP-26-99F	175.00	115.00	290.00
Controls		Thermostat	85.00	60.00	145.00
Ductwork		-----	890.00	1,600.00	2,490.00
Interior piping		-----	420.00	530.00	950.00
Total HVAC Installation Cost					\$ 11,633.00
Total Project Cost					\$ 17,013.00

*The only maintenance cost that the geothermal system has incurred is the \$70.00 for the filter that needs to be changed once a year.

Table 4.40. HVAC Installation Cost for CH3

HVAC	Total Cost
Equipment (A/C unit)	2,700.00
Materials	500.00

Table cont'd.

HVAC	Total Cost
Ductwork	2,000.00
Labor	4,500.00
Permits, inspection	65.00
Total HVAC Installation Cost	\$ 9,765.00

*Owner estimates \$200 spent on yearly maintenance (filters, Freon check, and equipment maintenance).

4.3.6. Consumption and Cost Data

The energy usage data collected for GH3 and CH3 included data from the monthly energy bills. The data includes 37 months of consumption (in kWh) and cost, from January 2014 through January 2017 for GH3, and 36 months of consumption (in kWh) and cost, from April 2014 through March 2017 for CH3. Both GH3 and CH3 utilize only electricity for energy, and therefore electricity consumption and costs are presented in Table 4.41.

Table 4.41. Energy Consumption and Usage Cost for GH3 and CH3

Year	Month	Electricity Consumption (kWh)		Electricity Usage Cost (USD)	
		GH3	CH3	GH3	CH3
2014	Jan	620		53.13	
	Feb	504		44.60	
	Mar	406		37.60	
	Apr	335	1110	34.20	113.33
	May	413	974	42.66	100.61
	Jun	528	1389	53.38	140.43
	Jul	671	1411	68.31	143.64
	Aug	760	1591	74.86	156.71
	Sep	770	1568	75.61	153.98
	Oct	602	1122	58.39	108.83
	Nov	568	1284	50.61	114.40
	Dec	439	1589	40.61	146.98
2015	Jan	503	1700	44.87	151.64
	Feb	552	1609	49.29	143.68
	Mar	780	1724	69.65	153.95
	Apr	667	1103	62.36	103.13

Table cont'd.

Year	Month	Electricity Consumption (kWh)		Electricity Usage Cost (USD)	
		GH3	CH3	GH3	CH3
	May	697	1116	68.31	109.37
	Jun	723	1039	67.82	97.46
	Jul	914	1455	85.55	136.19
	Aug	1071	1677	103.99	162.84
	Sep	1031	1221	100.21	118.68
	Oct	965	1133	93.12	109.33
	Nov	689	903	63.04	82.62
	Dec	715	1104	62.99	97.26
2016	Jan	780	1367	66.30	116.20
	Feb	729	1231	61.67	104.14
	Mar	803	1176	73.31	107.37
	Apr	720	863	66.02	79.14
	May	590	939	54.75	87.14
	Jun	1015	1177	90.94	105.46
	Jul	1067	1373	96.67	124.39
	Aug	1048	1203	98.83	113.44
	Sep	1072	1378	102.05	131.19
	Oct	1071	1261	99.92	117.65
	Nov	825	1039	75.57	95.17
	Dec	790	785	72.05	71.59
2017	Jan	803	1432	61.91	110.41
	Feb		847		65.30
	Mar		809		62.37

4.3.7. Comparison of Electricity Consumption and Cost

The statistical analyses used for the collected consumption and cost data is the analysis of variance (ANOVA) test. Electricity consumption was collected from GH3 and CH3 and converted to electricity usage cost using the table shown in Appendix D. In conducting an appropriate ANOVA, three tests must be completed, which includes analyzing the shape of the data (test for normality), the spread of the data (test for homogeneity of variance), and the location of the data (ANOVA test of means). The sections below outline the results of the ANOVA for comparing GH3 to CH3.

4.3.7.1. Descriptive Statistics

Using SPSS, the descriptive statistics for the two cases in case study #3 is provided in Table 4.42 (energy consumption) and Table 4.43 (energy usage cost). In review of the descriptive statistics, GH3 has a much lower average consumption and cost than CH3, which provides initial evidence that GH3 uses less energy and cost less to operate than CH3.

Table 4.42. Descriptive Statistics of the Electricity Consumption in Case Study #3

HVAC System	Mean	Std. Deviation	Variance	Minimum	Maximum	Range	N
Geothermal (GH3)	677.21	191.04	36494.52	335.00	1071.00	736.00	24
Conventional (CH3)	1241.7	265.39	70431.92	785.00	1724.00	939.00	36

Table 4.43. Descriptive Statistics of the Electricity Usage Cost in Case Study #3

HVAC System	Mean	Std. Deviation	Variance	Minimum	Maximum	Range	N
Geothermal (GH3)	63.82	17.41	303.03	32.13	99.71	67.58	24
Conventional (CH3)	115.51	25.59	654.90	71.36	160.50	89.15	36

4.3.7.2. Test for Normality

The test for normality requires the review of the Anderson-Darling (A-D) goodness of fit test, and the skewness and kurtosis of the data to determine if the data is normally distributed. Using the MVP Stats statistical program, the A-D values, and skewness and kurtosis values were calculated and presented in Table 4.44 and 4.45 below. Based on the results, the data for energy consumption is approximately normally distributed as the p-values are 0.05 or greater for A-D values, and skewness and kurtosis for GH3 and CH3. Then, for energy usage cost the p-values are greater than 0.05 for the four tests, meaning that the energy usage data from GH3 and CH3 can be approximated by the normal distribution.

Table 4.44. Normality Test for Electricity Consumption in Case Study #3

Case	A-D	p-value
GH3	0.392	0.382
CH3	0.317	0.561

Table 4.45. Normality Test for Electricity Usage Cost in Case Study #3

Case	Skewness	p-value	Kurtosis	p-value
GH3	0.964	0.534	0.204	0.561
CH3	0.958	0.187	0.139	0.629

4.3.3.7. Test for Homogeneity of Variance

Establishing normality means that the homogeneity of variance can be analyzed using Levene's Statistic for energy consumption based on the absolute deviation from the average values (ADAs), which were calculated in MVP Stats and transferred to SPSS to conduct the homogeneity of variance test. The results of the homogeneity of variance test for energy consumption is provided in Table 4.46. The results show non-significance at the 5% level, meaning that one can infer the variances are the statistically the same between GH3 and CH3.

Table 4.46. Test of Homogeneity of Variances for Electricity Consumption in Case Study #3

Levene's Statistic	p-value
1.131	0.292

With normality not established for the energy usage cost data, Levene's statistic can still be used, but the homogeneity of variance test needs to be run using the absolute deviation from the median values (ADMs). With the lack of normality and using ADM values, the results are more approximated than when normality is established and ADA values are used. Table 4.47

displays the results of the homogeneity of variance test for the energy usage cost data. The results show non-significance with a p-value greater than 0.05. This means that one can infer that the variance values for GH3 and CH3 are the same.

Table 4.47. Test of Homogeneity of Variances for Electricity Usage Cost in Case Study #3

Levene's Statistic	p-value
3.457	0.068

4.3.7.4. One-Way ANOVA of the Means

With normality and homogeneity of variance established for the energy consumption data, a one-way ANOVA can be performed using SPSS. The results of the ANOVA of the means for GH3 and CH3 are presented in Table 4.48. With the p-value less than 0.05, the results show that average energy consumption for GH3 is not equal to the average energy consumption of CH3. Therefore, the point estimate mean energy consumption value for GH3 is 677.21 kWh/month while the point estimate for CH3 is 1241.72 kWh/month.

Table 4.48. Comparison of the Electricity Consumption Mean using ANOVA for Case Study #3

	F	p-value
Case Study 3 ANOVA	80.544	<0.05

For the lack of normality and unequal variances, the ANOVA of the means for the energy usage cost data can be conducted using Welch's statistic. Welch's statistic is a form of ANOVA that is robust to lack of homogeneity of variance by using an asymptotically distributed F-test. The results of the Welch ANOVA are presented in Table 4.49. The p-value is less than 0.05, meaning that the average energy usage costs are different between GH3 and CH3. The average monthly energy usage cost is \$63.82 for GH3 and \$115.51 for CH3.

Table 4.49. Robust Tests of Equality of Means for Electricity Usage Cost in Case Study #3

	Statistic	p-value
Case Study 3 Welch ANOVA	86.696	<0.05

4.3.8. Payback Period

Figure 4.6 illustrates the payback period for GH3 in comparison to CH3 for the cost of the geothermal system with and without applied federal tax credits. The payback period for GH3 is 3.5 years with the tax credit and 12 years without the tax credit. Therefore, case study 3 demonstrates that tax credits allow geothermal heat pumps to become more affordable for average-size homes in hot and humid climates.

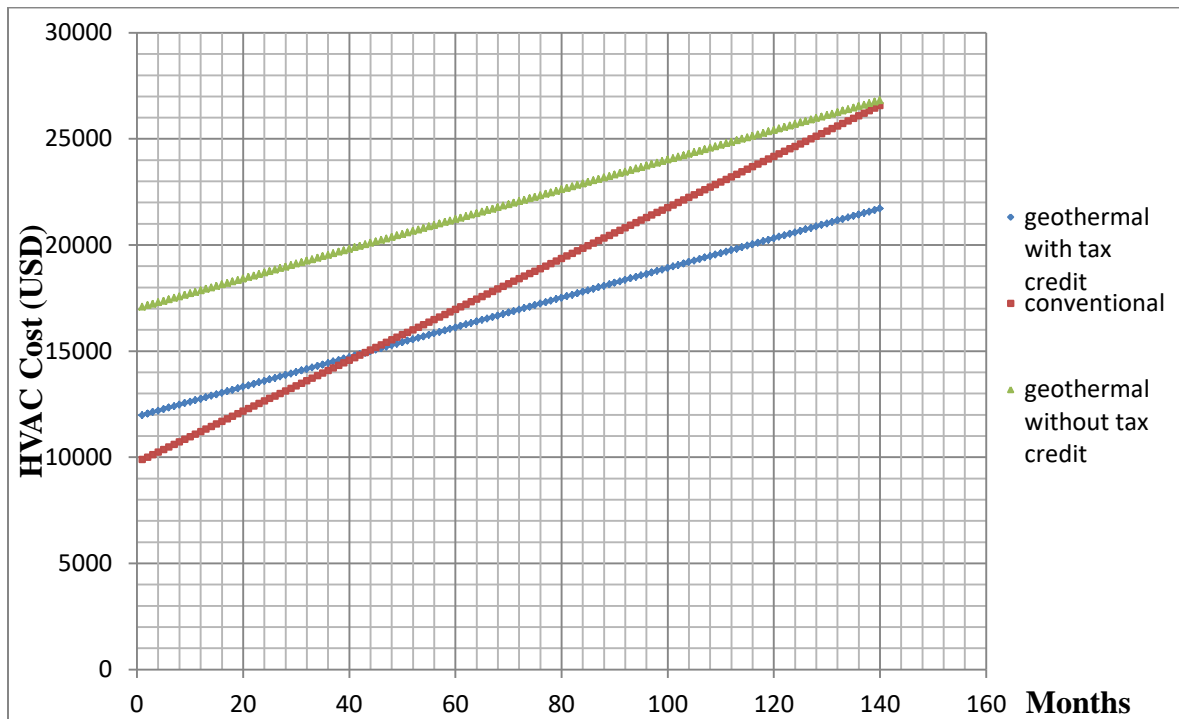


Figure 4.6. Payback Period of GH3 in Case Study #3

4.3.9. Occupant Satisfaction

The occupants for each case study answered six questions about the perception of their HVAC system. The questions asked how satisfied the homeowners are in terms of cooling comfort, heating comfort, indoor air quality, acoustics, maintenance, and thermostat settings. The results of the satisfaction questions are shown in Table 4.50.

Table 4.50. Occupant Satisfaction for GH3 and CH3

Aspect	G H3 R ating	C H3 R ating
Cooling Comfort	5/5	4/5
Heating Comfort	5/5	4/5
Indoor Air Quality	5/5	4/5
Acoustics	5/5	4/5
Maintenance Frequency and Response	5/5	4/5
Thermostat Settings	5/5	4/5

4.4. Case Study 4

4.4.1. General Information

GH4 is a single family residence built in 1890 and is located in New Orleans, LA. It is a one story building with a floor area of 1,800 square ft. and a total of two occupants. On July 2012 the owners decided to retrofit the house with a geothermal heat pump system and solar PV panels, before the house only used window A/C units. Homeowners received state and federal incentives for the installation of energy efficient equipment.

The following paragraphs will describe the building use, type of material and level of insulation of GH4 shell components: interior wall, exterior wall, roof, floor, and windows. Case Study #4 did not have enough monitored data to calculate the payback period as in the previous case studies. However, the qualitative information collected from GH4 provides practical

guidelines for residential owners that consider installing a GHP system for heating and cooling. This case will be further discussed in chapter 5.

4.4.2. Building Shell Features

The building shell information includes the framing structure for walls, roofs, and floors, the insulation for walls, roofs, and floors, and window information. The framing material and type of insulation were gathered from the survey (Appendix A) given to the owner. Table 4.51 presents the building shell for GH4.

Table 4.51. Building Shell Features of GH4

Framing	Material	Type of insulation
Walls	Wood	Foam, fiberglass
Roof	Wood with asphalt shingles. Small portion is standing seam metal roof.	4 inches closed-cell foam
Floor	Wood	Foam board
Windows	Old, single pane glass. Two windows are new double pane	Plexiglass covers

4.4.3. Lights & Appliance Features

GH4 has 30 compact fluorescent light bulbs. Table 4.52 outlines the type and number of appliances found in GH4.

Table 4.52. Appliance Quantities of GH4

Appliance	Quantity	Appliance	Quantity
Water Heater	1	Iron	0
Refrigerator	1	Hair Dryer	0
Washing Machine	1	Vacuum Cleaner	1
Clothes Dryer - Electric	0	Ceiling / Portable Fans	8
Clothes Dryer - Gas	1	TV	1
Dishwasher	1	DVD/Blu-Ray Player	1

Table cont'd.

Appliance	Quantity	Appliance	Quantity
Sink Waste Disposal	0	Desktop Computer	0
Microwave	1	Laptop Computer	2
Toaster Oven	1	Printer/Scanner	1
Toaster	0	Stereo	2
Electric kettle/pans	1	Clock Radio	1
Range - Electric	0	Cable Box	0
Range - Gas	1	Internet Router	1
Coffee Machine	0	Battery Chargers	2
Blender	1	Other, Please list:	Landline with battery backup

4.4.4. Mechanical Features

GH4 has a geothermal heat pump system to supply heating and cooling to the house. The system was installed in 2012. The GHP system uses a closed-loop ground heat exchanger. The ground heat exchanger consists of six drilled vertical boreholes between 120 ft. to 175 ft. deep. High density polyethylene (HDPE)/Pro PEX U-tube runs through each borehole. The diameter of the drilled borehole is 4 inches and U-tube diameter is $\frac{3}{4}$ inches. The diameter of the ground loop header is 1 inch and the material is HDPE. The 4-ton capacity, water-to-air heat pump unit brand is BOSCH.

4.4.5. Material, Maintenance & Installation Costs

The material and installation cost of the GHP system installed in GH4 were obtained from the owner and installer. The owner had an invoice of \$26,080 for total project cost. The installer was able to provide few itemized costs. Tables 4.53 and 4.54 outline the ground loop cost and the geothermal HVAC system installation cost for GH4. The system had a 10-year warranty; therefore no maintenance cost was available.

Table 4.53. Ground Loop Installation Cost for GH4

Ground Loop	Unit	Qty.	Equipment/ Material	Labor	Total Cost
Drilling	ft			8,700.00	8,700.00
Grouting	ft ³				-----
Pipes & Fittings	ft				2,450.00
Exterior headers	ft				420.00
Total Ground Loop Installation Cost					\$ 11,570.00

Table 4.54. HVAC Installation Cost for GH4

HVAC	Qty	Model	Equipment/Material	Labor	Total Cost
Heat pump	1	WaterFurnace LDV024	6,125.00	2,110.00	8,235.00
Water pump	1	Grundfos UP-26-99F	875.00	200.00	1,075.00
Controls		Thermostat			-----
Ductwork		-----			-----
Interior piping		-----			-----
Total HVAC Installation Cost					\$ 14,510.00
Total Project Cost					\$ 26,080.00

4.4.5. Occupant Satisfaction

The occupants for each case study answered six questions about the perception of their HVAC system. The questions asked how satisfied the homeowners are in terms of cooling comfort, heating comfort, indoor air quality, acoustics, maintenance, and thermostat settings. The results of the satisfaction questions for GH4 are shown in Table 4.55.

Table 4.55. GH4 Occupant Satisfaction

Aspect	GH4 Rating
Cooling Comfort	4/5
Heating Comfort	3/5
Indoor Air Quality	5/5
Acoustics	2/5
Maintenance Frequency and Response	2/5
Thermostats Settings	3/5

CHAPTER 5: DISCUSSION

Throughout this investigation the lack of knowledge in GHP systems became evident in Louisiana. Few HVAC contractors were familiarized with non-traditional systems and even fewer were experienced GHP installers. The GHP market in southern Louisiana is currently shared by two or three contractors. In the middle of this incredible low market competition, this study was able to collect cost and/or performance data from four case studies.

On each case study, homeowners shared their experience of having a GHP system and their level of satisfaction was measured by using a typical five-level Likert scale. The following paragraphs will discuss the findings on each case study, especially the factors that contributed to these findings. For instance, how the use of tax incentives made a positive impact when funding GHP systems, or how the lack of experienced GHP installers (low market competition) negatively affected the cost and performance of GHPs.

5.1. Case Study 1 (GH1 and CH1)

Starting with case study 1, this particular case study presents the most expensive GHP system installation relative to the building floor area. More than 50% of the total GHP system cost belongs to the interior components. Within the interior components, the GHP equipment itself represents nearly half of the HVAC cost. Since this is a new construction the ductwork also represents a significant portion of the cost. The third major expense comes from the system controls. The owners of GH1 have access to an online database that monitors utility consumption/production daily. Thus, GH1 system controls are more sophisticated than most regular homes. In addition to the sophisticated system controls, the GHP system design includes a cooling tower and a rainwater harvesting tank. Obviously these two items increase the complexity of the design and cost (extra piping, more equipment, labor, etc.) According to

geothermal experts, the cooling tower is an unnecessary expense for such a relatively small single family home.

This GHP system had technical issues after three years of being in operation, which required maintenance and inspection from a third party (not involved at the time of design/installation). While it is highly recommended the design and installation of GHP systems to be a single party job [Konrad, 2014], in this case multiple parties were involved. The design drawings were developed by a MEP engineering group, the excavation and ground loop installation were done by two different small contracting companies, the HVAC was installed by a well-known local contractor, and the architect, who was involved in the building's construction. From interviews with some of the major parties involved in the project it can be said that the amount of parties involved combined with a steep learning curve (first GHP installation) negatively affected the "team" relationship and it was ultimately reflected on the system cost and performance.

When comparing GH1 to CH1, which uses an air-source heat pump instead, it was no surprise the huge difference on installation cost. The savings in utility services, on the other hand, were as expected. But even though utility monthly expenses are almost half of CH1 expenses, the payback period of GH1 is 32 years taking into account the 30% residential tax credit, without the tax credit it stretches to 73 years. The extensive payback period is a result of multiple parties involved in the design and installation, the inclusion of unnecessary components (e.g., cooling tower), and a lack of understanding of geothermal heat pump systems in hot and humid climates

5.2. Case Study 2 (GH2)

Case study 2 is the only case in this research that has retrofitted a GHP system in an existing home. The size of building GH2 is over twice the size of building GH1, but remains in the average home size category. The interior components once again account for more than half of the total project cost. The heat pump and system controls are the biggest expenses of the interior components. The capacity of the heat pump is slightly on the heavier side for a residential dwelling (7 tons) and the building uses a 3-zone intelligent thermostat.

The difference in electricity bills before and after geothermal are very noticeable in this case (all electricity and no gas). The electricity bills decreased from an average of \$350 to \$130 every month which is about 60% less. The overall satisfaction of the owner with the GHP system is very high. The owner mentioned that insulation work was performed before installing the geothermal heat pump system to improve the shell of the building. It was also mentioned that the homeowner conducted their own research before making the purchase of the system.

The designer/installer of this GHP system is certified by the International Ground Source Heat Pump association (IGSHPA) and has over 30 years of experience with conventional and geothermal HVAC systems. Case study 2 demonstrates that a well-educated owner along with a certified geothermal installer, the payback period on the investment can be less than five years in this case it was within the first 2 years of operation (using the 30% tax credit), without the tax credit the payback period is approximately 7 years. Therefore, case study 2 demonstrates that tax credits or incentives can make a difference and enable clean technologies, such as GHPs, to be affordable to the average household. Case study 2 also shows that geothermal heat pump systems can be retrofitted to existing homes and can perform well in hot and humid climates.

5.3. Case Study 3 (GH3 and CH3)

The building in case study 3, GH3, is slightly larger than GH1 and yet uses a geothermal heat pump of less capacity (2 tons). The installation cost of the HVAC is approximately 50% higher than the installation of the ground loop. The heat pump is the most expensive item within the HVAC components. In this case the geothermal installer had its own drilling equipment therefore the cost for the ground loop installation may have been lower than usual. Similar to the GHP system in GH2, the only maintenance that the system has gone through is the heat pump filter which needs to be changed once a year. Currently the heat pump filter retails for \$70.

The owner is very satisfied with the GHP system performance and with the electricity bills (all electricity and no gas). When compared to CH3 the cost for electricity is around 40% less. From the utility savings and subtracting 30% from the initial cost, using the applied tax credit, the payback period is 3.5 years. Otherwise, without the tax credit payback period extends to almost 12 years.

5.4. Case Study 4 (GH4)

For case study 4, although the usage and cost data was unavailable, the researcher realized this case has a few interesting points that might be useful for potential future GHP owners. To start, it is important to research the GHP system and installers. GHPs have several benefits and they are suitable for almost every residence; however, it is very important that the building is well-insulated. The house in case study 4 (GH4) was built in 1890 and had a poor insulation especially through the windows and walls, which did not help to save as much energy as it would with a better insulation.

Second, it is advised to hire a certified contractor to install a GHP system with experience in geothermal heat pump systems. An issue with GH1 was that the geothermal contractor, who

designed and installed the system, was unable to provide a design of the system and admitted that they did not have experience with GHP systems prior to this project. The contractor in case study 4 never showed a blueprint and when interviewed and questioned about obtaining the design, the contractor answered, “it is all up here”, as he pointed to his head, referring that the design was never documented and was all in his head. This contractor was not an engineer nor certified by the IGSHPA, and GH4 was actually the first GHP system the contractor ever attempted.

Third, do not assume that conventional A/C contractors and Solar PV installers are also experts in GHPs. The contractor in case study 4 originally installed solar panels on the house and convinced the owners to install geothermal as a “one package deal”. But the contractor had zero experience with GHPs and literally used GH4 as an experiment. Therefore, it is important to request experience information from a contractor to prove successful prior GHP installations.

Fourth, in order to avoid any risk of saturation or heat accumulation around the ground loop in hot climates, the GHP system must operate all year round even during the winter season. Sometimes homeowners are not well informed in how to properly operate a GHP system. Homeowners of GH4 let the GHP system operate only when outside air was extremely hot, otherwise they kept the system off. This negatively affected the performance of the GHP system by not letting the heat absorbed during the summer to be released during the winter. This kind of behavior seen in homeowners arises from the idea that the longer the A/C is off the lower the energy bills. Nevertheless, the constant change of temperature in the thermostat settings can increase energy consumption. Furthermore, GHPs have already been proven to consume little electricity compared to conventional air-source systems, so using a GHP constantly will only slightly increase energy consumption.

The owners of GH4 are individuals that genuinely care about the environment and try to afford a more sustainable lifestyle. However, as this case illustrates, there are contractors that call themselves GHP designers/installers that are truly not qualified and end up not providing the right system or the right quality. This kind of situation consequently discourages homeowners to invest on GHPs.

5.5. Comparison of Case Studies

Investigating across all of the case studies provides additional discussion points. In terms of payback period, shown in Table 5.1, GH2 experienced the shortest payback period with GH1 experiencing the longest payback period. GH2 experienced comparable results to GH3. Therefore, GH2 and GH3 provide evidence that GHPs can be affordable and provide a quick payback period on their investment, but only when using a knowledgeable and experienced geothermal heat pump system designer and installer. In the case of GH1, the multiple parties involved and the overdesign and inclusion of unnecessary components drastically increased the installation cost to a point that the payback on the investment is irrelevant.

Table 5.1. Payback Period of the GHP System Investment with and without Tax Credit

Residence ID	Payback Period with Tax Credit	Payback Period without Tax Credit
GH1	32	73
GH2	2	7
GH3	3.5	12
GH4	NA	NA

For occupancy satisfaction, Table 5.2 outlines the results from each of the geothermal case study homes. Each of the four geothermal heat pump system homes noted either very satisfied or satisfied for providing comfort during hot and humid periods of the year. This finding

shows that geothermal heat pump systems can perform just as well as conventional HVAC systems in hot and humid climates, such as southern Louisiana.

Table 5.2. Occupancy Satisfaction for Case Studies

	Case Study #1		Case Study #2		Case Study #3		Case Study #4
	GH1	CH1	GH2	CH2	GH3	CH3	GH4
Cooling Comfort	5	4	5	4	5	4	4
Heating Comfort	3	4	5	4	5	4	3
Indoor Air Quality	5	3	5	4	5	4	5
Acoustics	5	3	5	3	5	4	2
Maintenance Frequency	4	4	5	4	5	4	2
Thermostat Settings	4	3	5	3	5	4	3

GH1 and GH4 noted issues with the system when needing to provide heat during cooling periods of the year. GH1 noted that the home tended to be on the cooler side on the first floor even with the GHP system running during the cooler months of the year. Then, GH4 noted similar issues, but part of the problem could be due to the age of the home (over 120 years old) and a lack of updated insulation to the building shell.

In regards to the acoustics, only GH4 had issues with it. The heat pump in GH4 was located in the attic above the bedroom, while in the rest of the cases the heat pump was located in a room nowhere near the bedroom. Therefore, the heat pump location and poor insulation might be the sources for the acoustics issues in GH4. GH4 once again rated the lowest for maintenance frequency and response.

The homeowners mentioned that the installer included a 10-year warranty in the contract. However, the installer seldom responded to the homeowner's concerns about the GHP system performance, and when responded, actions were taken without been properly explained. For

example, the expansion tank was removed because GH4 did not “need” it anymore. Despite of the numerous attempts of the homeowner to obtain a sketch of the design from the installer, this always seemed to be ignored. Unfortunately, Louisiana lacks of certified GHP system designers/installers, and without a sketch of the system, homeowners of GH4 had even a harder time to find technical assistance.

GH1 was also not fully satisfied with the maintenance frequency and response. Nevertheless, GH1 did have blueprints and construction specifications of the building and the geothermal heat pump system, which allowed for inspections or technical assistance from third parties. The thermostat equipment in GH1 was more updated than that of GH4, but in both cases the homeowners needed better instructions for utilizing the thermostat settings.

Overall, homeowners felt more satisfied with the performance of GHP systems than with the performance of conventional air-source systems in hot and humid climate.

CHAPTER 6: CONCLUSIONS

This study was able to collect performance and cost data from three residential buildings in Louisiana with geothermal heat pump (GHP) systems installed for space heating and cooling. Two of the buildings were classified as new construction and one as a retrofit. For the new construction buildings, data from other two buildings with matching characteristics and installed conventional air-source systems was collected. Existing data was gathered using the survey attached in Appendix A. Additional information was obtained through on-site visits, conference calls, and electronic means. The data was organized into three case studies, each case study having a geothermal and conventional type of HVAC system.

6.1. Primary Results and Conclusions

Based on the case studies the following could be drawn:

- The initial cost of a GHP system is approximately twice the initial cost of a conventional air-source system.
- Energy usage cost can be in average 60% less with GHPs.
- Assuming a 30% tax credit the payback period of a GHP system with a vertical ground heat exchanger (GHX) installed in an average size household in southern Louisiana can be as little as 2 years.
- Without the 30% tax incentive the payback period can be four times longer.
- Tax credits can make GHP systems more affordable to average-size households as the payback period is extensively long without the tax credits.
- The contractor base for GHPs in southern Louisiana is in its infancy, which can lead to systems not performing well or costing more than expected.

- Homeowners feel more satisfied with the performance of a GHP system than with the performance of a conventional air-source system in a hot/humid climate.
- GHP monitoring to track system performance should be included in the GHP system to help collect real data and overcome trust issues or uncertainty towards this technology.

6.2. Limitations

The main limitation that this study encountered was the time restriction. Therefore, only three case studies were analyzed given the complexity of the data collection as described in chapter 4. The second most important limitation was that only cost, performance, and energy consumption data were collected from the case studies. This research did not collect supply and return temperatures, flow rates, or other critical design and performance criteria in order to determine whether or not the geothermal heat pump (GHP) system presented a good design or efficiency.

Also, human factors and the use of the case study homes varied, meaning that slight differences existed between the GHP homes and conventional HVAC homes even though the physical building structures of the cases were similar. As is common in case study research, some factors, such as when people decide to turn lights on or off, are difficult to control.

The third limitation was the low number of GHP system installers available in southern Louisiana along with a lack of willingness to share itemized cost information for this research study. A limited amount of GHP system contractors exist within Louisiana, and of these contractors, more were not willing to share data than the contractors that did share their data for this research. This limitation dictated which cases could be investigated fully in this study.

6.3. Future Research

The author decided to do research in GHPs based on the fact that unlike other well-known sustainable technologies, such as solar panels and wind turbines, this type of technology is almost “invisible” and barely known after being around in the HVAC industry since the 70s. Therefore, the opportunities for research in GHPs are still numerous. For instance, GHPs are more popular in northern states where the heating loads are higher and fossil fuel derivatives are more expensive. Some research efforts have been done in order to increase awareness on the residential applications of GHPs in hot/humid climates, but very few have used real data to compare the cost and performance of GHPs with other types of HVAC systems.

More work needs to be done in collecting real, updated data, using a other research methods besides a field survey in order to obtain more samples and therefore perform larger scale investigations. The benefits of the pond/lake loop configuration for hot/humid climates also need to be further investigated by implementing real data as this configuration was not studied in this research due to a lack of finding a homeowner willing to participate in this study.

Finally, it would be useful to investigate the current geothermal market in southern Louisiana as there seems to be a lack of policies or regulations in place for GHP systems as well as a lack of knowledge and experience with GHP systems in hot and humid climates found along the Gulf Coast.

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APPENDIX A; GEOTHERMAL CASE STUDY PROTOCOL QUESTIONNAIRE



College of
Engineering
Bert S. Turner

Department of Construction Management

Welcome! We appreciate your willingness to participate in this research project. This research study is crucial to help researchers and practitioners better understand the performance and costs associated with geothermal heat pump systems. Your participation is completely on a volunteer basis and your responses and data provided will be coded and kept confidential. Your responses will not be reported in any manner that can be associated with any specific individual, organization, project, agency, or program.

The survey consists of six sections:

- I. Building information
- II. Geothermal heat pump system general information
- III. Geothermal heat pump system design and installation costs
- IV. Geothermal heat pump system maintenance, service, repair costs
- V. Available metered/monitored data
- VI. Occupant satisfaction

Please provide as much information as you can. If you do not know the answers for some of the questions, you may need to contact the associated parties (a contractor, an engineer, etc.) that performed the work. Alternatively, you may provide contact information for the associated parties to our project team and we will contact them to collect any remaining data.

If you require assistance in completing the questionnaire, please contact Claudia Duran at (504)975-5687 or cduran7@lsu.edu. If you have any questions or concerns about this research project, please contact Christofer Harper at (225)578-0131 or charper@lsu.edu.

As a follow up to this survey, you may be contacted via phone, email, or other electronic means to discuss the data provided. If possible, our project team may need to visit your site(s) to perform an on-site data validation.

Thank you for sharing your experience with your geothermal heat pump system. You will help create opportunities in consulting, construction industry, financial institutions, geothermal heat pump manufacturers and utility companies in making decisions for adopting geothermal heat pump system technology.

I understand the above information and voluntarily consent to participate in the research questionnaire

- ☐ Yes, continue with survey
- ☐ No, opt out of survey

I. Building information

1. Owner full name: _____
2. Address/City/State/Zip Code: _____
3. Type of building (residential, commercial, etc.): _____
4. Year building constructed: _____
5. Floor area, [ft²]: _____
6. Number of stories: _____
7. Total occupants: _____
8. Type of light bulbs (mark all that apply):
☐ Incandescent ☐ Halogen ☐ CFLs ☐ LEDs
9. Approximate number of light bulbs: _____
10. Approximate number of fluorescent tubes: _____

11. Fill the table below with the quantity of household appliances

Appliance	Quantity	Appliance	Quantity
Water heater		Iron	
Refrigerator		Hair dryer	
Washing machine		Vacuum cleaner	
Clothes dryer - electric		Ceiling/portable fan	
Clothes dryer - gas		TV	
Dishwasher		DVD player	
Sink waste disposal		Desktop computer	
Microwave		Laptop computer	
Toaster oven		Printer/scanner	
Toaster		Stereo	
Electric kettle/pans		Clock radio	
Stove & oven – electric		Cable box	
Stove & oven – gas		Internet router	
Coffee machine		Battery charges	
Blender			
Other, please list:		Other, please list:	

12. Use the table below to indicate the material and insulation (if applicable) of the following:

Building envelope	Material	Type of insulation
Walls		
Windows		
Roof		
Floor		

II. Geothermal heat pump system general information

13. System installation initial and end date (month/year): _____

14. Type of system

☐ Closed-loop ☐ Open-loop ☐ Surface-water ☐ Other, please list:

15. Type of loop

☐ Vertical ☐ Horizontal ☐ Spiral

16. Exterior headers material (pipes from well to heat pump): _____

17. Diameter of exterior headers, [in]: _____

18. Total length of pipe (underground and exterior), [ft]: _____

19. Number of heat pump units: _____

20. Type of heat pump (water-to-air, water-to-water, other): _____

21. Capacity per unit, [Ton] or [W]: _____

22. Number of circulation or water pumps: _____

23. Capacity per water pump, [Ton] or [W]: _____

24. Does your geothermal heat pump system utilize an auxiliary heat rejecter (cooling tower)?

☐ YES ☐ NO

25. If yes to question 24, Capacity of cooling tower, [Ton] or [W]: _____

26. Capacity of cooling tower pump, [Ton] or [W]: _____

27. Does your geothermal system provide free hot water?

☐ YES ☐ NO

28. Type of incentives used:

☐ State ☐ Federal ☐ Municipal ☐ Utility ☐ Other, please list:

29. Name of company or contractor(s) who designed and installed your geothermal system:

If Vertical:

30. Number of boreholes: _____

31. Diameter of hole, [in]: _____

32. Depth of hole, each [ft]: _____

33. Grout material: _____

34. Number of U-tubes per borehole: _____

35. U-tube material (underground): _____

36. Diameter of U-tube, [in]: _____

If Horizontal:

37. Buried pipe depth, [ft]: _____

38. Length of buried pipe, [ft]: _____

39. Diameter of pipe, [in]: _____

III. Geothermal heat pump system design and installation costs

40. Fill the tables below with the following cost information:

Ground Loop	Unit	Qty.	Material	Equipment	Labor	Total Cost
Drilling	ft		-----	\$	\$	\$
Grouting	ft ³		\$	\$	\$	\$
Pipes & Fittings	ft		\$	\$	\$	\$
Exterior headers	ft		\$	\$	\$	\$
Other			\$	\$	\$	\$
Total Ground Loop Installation Cost						\$
Total Cost per Bore foot						\$

HVAC	Qty.	Model/Type	Material	Equipment	Labor	Total Cost
Heat pump			\$	\$	\$	\$
Water pump			\$	\$	\$	\$
Controls			\$	\$	\$	\$
Cooling tower			\$	\$	\$	\$
Ductwork		-----	\$	\$	\$	\$
Interior piping		-----	\$	\$	\$	\$
Other			\$	\$	\$	\$
Total HVAC Installation Cost						\$
Engineering Design (mechanical and/or civil) Cost						\$
Total Project Cost						\$

IV. Geothermal heat pump system maintenance, service, repair costs

41. Do you have a service and maintenance contract covering all labor and materials?

☐ YES ☐ NO

42. If YES for question 41, provide annual cost of contract: _____

43. Name of service and maintenance provider(s): _____

44. For both scheduled maintenance (where applicable) and unscheduled maintenance undertaken for the past five years, record all labor and material costs whether or not the work was completed under warranty, and whether or not the work was undertaken by your organization or an outside service and maintenance provider. Also provide a small description for the reason of maintenance.

	Scheduled		Unscheduled	
	Maintenance	Description	Maintenance	Description
2015	Labor		\$	
	Material			
2014	Labor			
	Material			
2013	Labor			
	Material			
2012	Labor			
	Material			
2011	Labor			
	Material			

V. Available metered/monitored data

45. Electricity consumption data [KWh]:

	2012	2013	2014	2015	2016
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					

46. Gas consumption data [ft³]:

	2012	2013	2014	2015	2016
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					

47. Supply and return ground loop temperatures, [F]: _____

48. Flow rate in ground loop, [gpm]: _____

49. Heat pump energy, [KWh]: _____

50. Water pump energy, [KWh]: _____

51. Cooling tower pump energy, [KWh]: _____

52. Cooling tower fan energy, [KWh]: _____

VI. Occupant satisfaction

53. Select the box that reflects your level of satisfaction with the **cooling season** indoor temperature and humidity:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

54. Select the box that reflects your level of satisfaction with the **heating season** indoor temperature and humidity:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

55. Select the box that reflects your level of satisfaction with the **air quality** (odors, stuffiness, air freshness):

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

56. Select the box that reflects your level of satisfaction with the **acoustics** (Heat/Cool equipment noise):

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

57. Select the box that reflects your level of satisfaction with the **reporting and responsiveness to building maintenance problems**:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

58. Select the box that reflects your ability to adjust the **thermostat settings** in your space:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

**APPENDIX B; CONVENTONAL HVAC SYSTEM CASE STUDY PROTOCOL
QUESTIONNAIRE**



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Bert S. Turner

Department of Construction Management

Welcome! We appreciate your willingness to participate in this research project. This research study is crucial to help researchers and practitioners better understand the performance and costs associated with geothermal heat pump systems. Your participation is completely on a volunteer basis and your responses and data provided will be coded and kept confidential. Your responses will not be reported in any manner that can be associated with any specific individual, organization, project, agency, or program.

The survey consists of six sections:

- I. Building information
- II. HVAC installation costs
- III. HVAC system maintenance, service, repair costs
- IV. Available metered/monitored data
- V. Occupant satisfaction

Please provide as much information as you can. If you do not know the answers for some of the questions, you may need to contact the associated parties (a contractor, an engineer, etc.) that performed the work. Alternatively, you may provide contact information for the associated parties to our project team and we will contact them to collect any remaining data.

If you require assistance in completing the questionnaire, please contact Claudia Duran at (504)975-5687 or cduran7@lsu.edu. If you have any questions or concerns about this research project, please contact Christofer Harper at (225)578-0131 or charper@lsu.edu.

As a follow up to this survey, you may be contacted via phone, email, or other electronic means to discuss the data provided. If possible, our project team may need to visit your site(s) to perform an on-site data validation.

Thank you for sharing your experience with your HVAC system. You will help create opportunities in consulting, construction industry, financial institutions, manufacturers and utility companies in making decisions for adopting sustainable HVAC systems such as geothermal heat pump systems.

I understand the above information and voluntarily consent to participate in the research questionnaire

- ☐ Yes, continue with survey
- ☐ No, opt out of survey

I. Building information

1. Owner full name:
2. Address/City/State/Zip Code:
3. Type of building (residential, commercial, etc.):
4. Year building constructed:
5. Floor area, [ft²]:
6. Number of stories:
7. Total occupants:
8. Type of light bulbs (mark all that apply):
9. ☐ Incandescent ☐ Halogen ☐ CFLs ☐ LEDs
10. Approximate number of light bulbs:
11. Approximate number of fluorescent tubes:

12. Fill the table below with the quantity of household appliances

Appliance	Quantity	Appliance	Quantity
Water heater		Iron	
Refrigerator		Hair dryer	
Washing machine		Vacuum cleaner	
Clothes dryer - electric		Ceiling/portable fan	
Clothes dryer - gas		TV	
Dishwasher		DVD player	
Sink waste disposal		Desktop computer	
Microwave		Laptop computer	
Toaster oven		Printer/scanner	
Toaster		Stereo	
Electric kettle/pans		Clock radio	
Stove & oven – electric		Cable box	
Stove & oven – gas		Internet router	
Coffee machine		Battery charges	
Blender			
Other, please list:		Other, please list:	

13. Use the table below to indicate the material and insulation (if applicable) of the following:

Building envelope	Material	Type of insulation
Walls		
Windows		
Roof		
Floor		

II. HVAC Installation Cost

Item	Model/Type	Equipment/Material	Labor	Total Cost
A/C Unit				
Ductwork	-----			
Controls				
Other				
Total HVAC Installation Cost				\$

III. Maintenance Cost

	Scheduled		Unscheduled	
	Maintenance	Description	Maintenance	Description
2015 Labor	\$		\$	
2015 Material				
2014 Labor				
2014 Material				
2013 Labor				
2013 Material				
2012 Labor				
2012 Material				
2011 Labor				
2011 Material				

IV. Available metered/monitored data

14. Electricity consumption data [KWh]:

	2012	2013	2014	2015	2016
January					
February					
March					
April					
May					

June					
July					
August					
September					
October					
November					
December					

15. Gas consumption data [ft³]:

	2012	2013	2014	2015	2016
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					

V.Occupant Satisfaction

16. Select the box that reflects your level of satisfaction with the **cooling season** indoor temperature and humidity:

☐ Very Dissatisfied
 ☐ Dissatisfied
 ☐ Acceptable
 ☐ Satisfied
 ☐ Very Satisfied

17. Select the box that reflects your level of satisfaction with the **heating season** indoor temperature and humidity:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

18. Select the box that reflects your level of satisfaction with the **air quality** (odors, stuffiness, air freshness):

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

19. Select the box that reflects your level of satisfaction with the **acoustics** (Heat/Cool equipment noise):

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

20. Select the box that reflects your level of satisfaction with the **reporting and responsiveness to building maintenance problems**:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

21. Select the box that reflects your ability to adjust the **thermostat settings** in your space:

☐ Very Dissatisfied ☐ Dissatisfied ☐ Acceptable ☐ Satisfied ☐ Very Satisfied

APPENDIX C; CONVENTIONAL HVAC SYSTEM QUOTE SHEET

FEATURES	OWNER 1	OWNER 2
Address	70131	70117
Building type	Single family residence	Single family residence
Foundation	----	Open crawlspace
Year constructed	2000	2009
Total SF	3000	1120
Number of Stories	2	2
Number of bedrooms	----	2
Total occupants	2	3
FRAMING MATERIALS		
Walls	Wood studs/brick	2x6 studs, 7/16" OSB sheathing, moisture barrier, 2" rigid foam board, 1x4 furring strips and siding
Wall insulation	Cellulose	R-20 spray foam
Windows	Vinyl Double Pane	Hurricane impact glass, No vinyl, Low-E
Window insulation	Low-E	U.35/SHGC.32
Roof	Seal Tab - Architectural	Rafters, sheathing, roofing membrane, insulation, membrane, metal roof
Roof insulation	Attic rafters are foam insulated	R-27 spray foam
Floor	1st floor tile /2nd floor hardwood flooring	Ground floor: joists, T&G PlyWood BlueWood treated floor for decking, 2" rigid insulation, underfloor insulation protection, rim boards, joist ties, sills, metal ties to sill. Second floor: second floor joists, subfloor, rim boards, joists ties
Floor insulation	Foam board	R-13
MECHANICAL SYSTEM		
Equipment	Conventional HVAC	Air-Source Heat Pump
Tonnage	7Ton (3 Ton upstairs and 4 Ton downstairs)	----
Model/Brand	York 16 SEER A/C with electric heat strip	Trane; electric Htg: 8.5 HSPF, Clg: 15.3 SEER
Ventilation system	----	None
Programmable thermostat	----	Cooling: Yes, Heating: Yes
TO QUOTE:		
Equipment (A/C unit)		
Materials (used for install)		
Ductwork		
Installation/labor		
Other, please list		
TOTAL PROJECT COST	\$	\$

**APPENDIX D; AVERAGE RETAIL PRICE FOR ELECTRICITY AND NATURAL GAS
FOR RESIDENCES IN LOUISIANA**

Average Retail Price of Residential Electricity in Louisiana in cents/kWh (Source: www.eia.gov)

Month	2012	2013	2014	2015	2016	2017
January	8.15	8.88	8.57	8.92	8.5	7.71
February	8.4	9.17	8.85	8.93	8.46	7.71
March	8.4	9.19	9.26	8.93	9.13	7.71
April	8.38	9.17	10.21	9.35	9.17	7.71
May	8.48	9.7	10.33	9.8	9.28	
June	8.01	9.7	10.11	9.38	8.96	
July	8.38	9.78	10.18	9.36	9.06	
August	8.29	9.76	9.85	9.71	9.43	
September	8.56	9.72	9.82	9.72	9.52	
October	8.68	9.68	9.7	9.65	9.33	
November	8.39	9.19	8.91	9.15	9.16	
December	8.47	8.76	9.25	8.81	9.12	

Average Retail Price of Natural Gas Delivered to Residential Customer in dollars/MCF (Source: www.eia.gov)

Month	2012	2013	2014	2015	2016	2017
January	9.62	9.15	9.26	9.5	8.32	9.38
February	9.47	9.23	9.77	9.08	8.39	10.05
March	10.41	9.35	10.7	9.28	9.19	
April	10.94	10.43	11.76	10.44	9.64	
May	12.61	12.61	13.6	12.73	11.6	
June	14.18	15.02	16.13	15.07	14.45	
July	15.13	16.3	17.23	16.28	16.57	
August	15.82	16.43	17.41	16.89	17.63	
September	14.72	15.69	16.27	16.4	16.81	
October	11.68	12.38	13.11	12.6	13.74	
November	9.99	10.04	10.19	10.02	10.76	
December	9.8	9.14	10.01	9.27	9.06	

APPENDIX E; PAYBACK PERIOD CALCULATIONS

Case Study 1 Payback Period Calculation Using Excel

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
Capital	28543.86		10954.50		28543.86	
Tax credit (30%)	9837.86					
Month		18706.00		10954.50		28543.86
1	25.00	18731.00	45.00	10999.50	25.00	28568.86
2	25.00	18756.00	45.00	11044.50	25.00	28593.86
3	25.00	18781.00	45.00	11089.50	25.00	28618.86
4	25.00	18806.00	45.00	11134.50	25.00	28643.86
5	25.00	18831.00	45.00	11179.50	25.00	28668.86
6	25.00	18856.00	45.00	11224.50	25.00	28693.86
7	25.00	18881.00	45.00	11269.50	25.00	28718.86
8	25.00	18906.00	45.00	11314.50	25.00	28743.86
9	25.00	18931.00	45.00	11359.50	25.00	28768.86
10	25.00	18956.00	45.00	11404.50	25.00	28793.86
11	25.00	18981.00	45.00	11449.50	25.00	28818.86
12	25.00	19006.00	45.00	11494.50	25.00	28843.86
13	25.00	19031.00	45.00	11539.50	25.00	28868.86
14	25.00	19056.00	45.00	11584.50	25.00	28893.86
15	25.00	19081.00	45.00	11629.50	25.00	28918.86
16	25.00	19106.00	45.00	11674.50	25.00	28943.86
17	25.00	19131.00	45.00	11719.50	25.00	28968.86
18	25.00	19156.00	45.00	11764.50	25.00	28993.86
19	25.00	19181.00	45.00	11809.50	25.00	29018.86
20	25.00	19206.00	45.00	11854.50	25.00	29043.86
21	25.00	19231.00	45.00	11899.50	25.00	29068.86
22	25.00	19256.00	45.00	11944.50	25.00	29093.86
23	25.00	19281.00	45.00	11989.50	25.00	29118.86
24	25.00	19306.00	45.00	12034.50	25.00	29143.86
25	25.00	19331.00	45.00	12079.50	25.00	29168.86
26	25.00	19356.00	45.00	12124.50	25.00	29193.86
27	25.00	19381.00	45.00	12169.50	25.00	29218.86
28	25.00	19406.00	45.00	12214.50	25.00	29243.86
29	25.00	19431.00	45.00	12259.50	25.00	29268.86
30	25.00	19456.00	45.00	12304.50	25.00	29293.86
31	25.00	19481.00	45.00	12349.50	25.00	29318.86
32	25.00	19506.00	45.00	12394.50	25.00	29343.86
33	25.00	19531.00	45.00	12439.50	25.00	29368.86
34	25.00	19556.00	45.00	12484.50	25.00	29393.86
35	25.00	19581.00	45.00	12529.50	25.00	29418.86

Table cont'd.

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
36	25.00	19606.00	45.00	12574.50	25.00	29443.86
37	25.00	19631.00	45.00	12619.50	25.00	29468.86
38	25.00	19656.00	45.00	12664.50	25.00	29493.86
39	25.00	19681.00	45.00	12709.50	25.00	29518.86
40	25.00	19706.00	45.00	12754.50	25.00	29543.86
41	25.00	19731.00	45.00	12799.50	25.00	29568.86
42	25.00	19756.00	45.00	12844.50	25.00	29593.86
43	25.00	19781.00	45.00	12889.50	25.00	29618.86
44	25.00	19806.00	45.00	12934.50	25.00	29643.86
45	25.00	19831.00	45.00	12979.50	25.00	29668.86
46	25.00	19856.00	45.00	13024.50	25.00	29693.86
47	25.00	19881.00	45.00	13069.50	25.00	29718.86
48	25.00	19906.00	45.00	13114.50	25.00	29743.86
49	25.00	19931.00	45.00	13159.50	25.00	29768.86
50	25.00	19956.00	45.00	13204.50	25.00	29793.86
51	25.00	19981.00	45.00	13249.50	25.00	29818.86
52	25.00	20006.00	45.00	13294.50	25.00	29843.86
53	25.00	20031.00	45.00	13339.50	25.00	29868.86
54	25.00	20056.00	45.00	13384.50	25.00	29893.86
55	25.00	20081.00	45.00	13429.50	25.00	29918.86
56	25.00	20106.00	45.00	13474.50	25.00	29943.86
57	25.00	20131.00	45.00	13519.50	25.00	29968.86
58	25.00	20156.00	45.00	13564.50	25.00	29993.86
59	25.00	20181.00	45.00	13609.50	25.00	30018.86
60	25.00	20206.00	45.00	13654.50	25.00	30043.86
61	25.00	20231.00	45.00	13699.50	25.00	30068.86
62	25.00	20256.00	45.00	13744.50	25.00	30093.86
63	25.00	20281.00	45.00	13789.50	25.00	30118.86
64	25.00	20306.00	45.00	13834.50	25.00	30143.86
65	25.00	20331.00	45.00	13879.50	25.00	30168.86
66	25.00	20356.00	45.00	13924.50	25.00	30193.86
67	25.00	20381.00	45.00	13969.50	25.00	30218.86
68	25.00	20406.00	45.00	14014.50	25.00	30243.86
69	25.00	20431.00	45.00	14059.50	25.00	30268.86
70	25.00	20456.00	45.00	14104.50	25.00	30293.86
71	25.00	20481.00	45.00	14149.50	25.00	30318.86
72	25.00	20506.00	45.00	14194.50	25.00	30343.86
73	25.00	20531.00	45.00	14239.50	25.00	30368.86
74	25.00	20556.00	45.00	14284.50	25.00	30393.86
75	25.00	20581.00	45.00	14329.50	25.00	30418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
76	25.00	20606.00	45.00	14374.50	25.00	30443.86
77	25.00	20631.00	45.00	14419.50	25.00	30468.86
78	25.00	20656.00	45.00	14464.50	25.00	30493.86
79	25.00	20681.00	45.00	14509.50	25.00	30518.86
80	25.00	20706.00	45.00	14554.50	25.00	30543.86
81	25.00	20731.00	45.00	14599.50	25.00	30568.86
82	25.00	20756.00	45.00	14644.50	25.00	30593.86
83	25.00	20781.00	45.00	14689.50	25.00	30618.86
84	25.00	20806.00	45.00	14734.50	25.00	30643.86
85	25.00	20831.00	45.00	14779.50	25.00	30668.86
86	25.00	20856.00	45.00	14824.50	25.00	30693.86
87	25.00	20881.00	45.00	14869.50	25.00	30718.86
88	25.00	20906.00	45.00	14914.50	25.00	30743.86
89	25.00	20931.00	45.00	14959.50	25.00	30768.86
90	25.00	20956.00	45.00	15004.50	25.00	30793.86
91	25.00	20981.00	45.00	15049.50	25.00	30818.86
92	25.00	21006.00	45.00	15094.50	25.00	30843.86
93	25.00	21031.00	45.00	15139.50	25.00	30868.86
94	25.00	21056.00	45.00	15184.50	25.00	30893.86
95	25.00	21081.00	45.00	15229.50	25.00	30918.86
96	25.00	21106.00	45.00	15274.50	25.00	30943.86
97	25.00	21131.00	45.00	15319.50	25.00	30968.86
98	25.00	21156.00	45.00	15364.50	25.00	30993.86
99	25.00	21181.00	45.00	15409.50	25.00	31018.86
100	25.00	21206.00	45.00	15454.50	25.00	31043.86
101	25.00	21231.00	45.00	15499.50	25.00	31068.86
102	25.00	21256.00	45.00	15544.50	25.00	31093.86
103	25.00	21281.00	45.00	15589.50	25.00	31118.86
104	25.00	21306.00	45.00	15634.50	25.00	31143.86
105	25.00	21331.00	45.00	15679.50	25.00	31168.86
106	25.00	21356.00	45.00	15724.50	25.00	31193.86
107	25.00	21381.00	45.00	15769.50	25.00	31218.86
108	25.00	21406.00	45.00	15814.50	25.00	31243.86
109	25.00	21431.00	45.00	15859.50	25.00	31268.86
110	25.00	21456.00	45.00	15904.50	25.00	31293.86
111	25.00	21481.00	45.00	15949.50	25.00	31318.86
112	25.00	21506.00	45.00	15994.50	25.00	31343.86
113	25.00	21531.00	45.00	16039.50	25.00	31368.86
114	25.00	21556.00	45.00	16084.50	25.00	31393.86
115	25.00	21581.00	45.00	16129.50	25.00	31418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
116	25.00	21606.00	45.00	16174.50	25.00	31443.86
117	25.00	21631.00	45.00	16219.50	25.00	31468.86
118	25.00	21656.00	45.00	16264.50	25.00	31493.86
119	25.00	21681.00	45.00	16309.50	25.00	31518.86
120	25.00	21706.00	45.00	16354.50	25.00	31543.86
121	25.00	21731.00	45.00	16399.50	25.00	31568.86
122	25.00	21756.00	45.00	16444.50	25.00	31593.86
123	25.00	21781.00	45.00	16489.50	25.00	31618.86
124	25.00	21806.00	45.00	16534.50	25.00	31643.86
125	25.00	21831.00	45.00	16579.50	25.00	31668.86
126	25.00	21856.00	45.00	16624.50	25.00	31693.86
127	25.00	21881.00	45.00	16669.50	25.00	31718.86
128	25.00	21906.00	45.00	16714.50	25.00	31743.86
129	25.00	21931.00	45.00	16759.50	25.00	31768.86
130	25.00	21956.00	45.00	16804.50	25.00	31793.86
131	25.00	21981.00	45.00	16849.50	25.00	31818.86
132	25.00	22006.00	45.00	16894.50	25.00	31843.86
133	25.00	22031.00	45.00	16939.50	25.00	31868.86
134	25.00	22056.00	45.00	16984.50	25.00	31893.86
135	25.00	22081.00	45.00	17029.50	25.00	31918.86
136	25.00	22106.00	45.00	17074.50	25.00	31943.86
137	25.00	22131.00	45.00	17119.50	25.00	31968.86
138	25.00	22156.00	45.00	17164.50	25.00	31993.86
139	25.00	22181.00	45.00	17209.50	25.00	32018.86
140	25.00	22206.00	45.00	17254.50	25.00	32043.86
141	25.00	22231.00	45.00	17299.50	25.00	32068.86
142	25.00	22256.00	45.00	17344.50	25.00	32093.86
143	25.00	22281.00	45.00	17389.50	25.00	32118.86
144	25.00	22306.00	45.00	17434.50	25.00	32143.86
145	25.00	22331.00	45.00	17479.50	25.00	32168.86
146	25.00	22356.00	45.00	17524.50	25.00	32193.86
147	25.00	22381.00	45.00	17569.50	25.00	32218.86
148	25.00	22406.00	45.00	17614.50	25.00	32243.86
149	25.00	22431.00	45.00	17659.50	25.00	32268.86
150	25.00	22456.00	45.00	17704.50	25.00	32293.86
151	25.00	22481.00	45.00	17749.50	25.00	32318.86
152	25.00	22506.00	45.00	17794.50	25.00	32343.86
153	25.00	22531.00	45.00	17839.50	25.00	32368.86
154	25.00	22556.00	45.00	17884.50	25.00	32393.86
155	25.00	22581.00	45.00	17929.50	25.00	32418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
156	25.00	22606.00	45.00	17974.50	25.00	32443.86
157	25.00	22631.00	45.00	18019.50	25.00	32468.86
158	25.00	22656.00	45.00	18064.50	25.00	32493.86
159	25.00	22681.00	45.00	18109.50	25.00	32518.86
160	25.00	22706.00	45.00	18154.50	25.00	32543.86
161	25.00	22731.00	45.00	18199.50	25.00	32568.86
162	25.00	22756.00	45.00	18244.50	25.00	32593.86
163	25.00	22781.00	45.00	18289.50	25.00	32618.86
164	25.00	22806.00	45.00	18334.50	25.00	32643.86
165	25.00	22831.00	45.00	18379.50	25.00	32668.86
166	25.00	22856.00	45.00	18424.50	25.00	32693.86
167	25.00	22881.00	45.00	18469.50	25.00	32718.86
168	25.00	22906.00	45.00	18514.50	25.00	32743.86
169	25.00	22931.00	45.00	18559.50	25.00	32768.86
170	25.00	22956.00	45.00	18604.50	25.00	32793.86
171	25.00	22981.00	45.00	18649.50	25.00	32818.86
172	25.00	23006.00	45.00	18694.50	25.00	32843.86
173	25.00	23031.00	45.00	18739.50	25.00	32868.86
174	25.00	23056.00	45.00	18784.50	25.00	32893.86
175	25.00	23081.00	45.00	18829.50	25.00	32918.86
176	25.00	23106.00	45.00	18874.50	25.00	32943.86
177	25.00	23131.00	45.00	18919.50	25.00	32968.86
178	25.00	23156.00	45.00	18964.50	25.00	32993.86
179	25.00	23181.00	45.00	19009.50	25.00	33018.86
180	25.00	23206.00	45.00	19054.50	25.00	33043.86
181	25.00	23231.00	45.00	19099.50	25.00	33068.86
182	25.00	23256.00	45.00	19144.50	25.00	33093.86
183	25.00	23281.00	45.00	19189.50	25.00	33118.86
184	25.00	23306.00	45.00	19234.50	25.00	33143.86
185	25.00	23331.00	45.00	19279.50	25.00	33168.86
186	25.00	23356.00	45.00	19324.50	25.00	33193.86
187	25.00	23381.00	45.00	19369.50	25.00	33218.86
188	25.00	23406.00	45.00	19414.50	25.00	33243.86
189	25.00	23431.00	45.00	19459.50	25.00	33268.86
190	25.00	23456.00	45.00	19504.50	25.00	33293.86
191	25.00	23481.00	45.00	19549.50	25.00	33318.86
192	25.00	23506.00	45.00	19594.50	25.00	33343.86
193	25.00	23531.00	45.00	19639.50	25.00	33368.86
194	25.00	23556.00	45.00	19684.50	25.00	33393.86
195	25.00	23581.00	45.00	19729.50	25.00	33418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
196	25.00	23606.00	45.00	19774.50	25.00	33443.86
197	25.00	23631.00	45.00	19819.50	25.00	33468.86
198	25.00	23656.00	45.00	19864.50	25.00	33493.86
199	25.00	23681.00	45.00	19909.50	25.00	33518.86
200	25.00	23706.00	45.00	19954.50	25.00	33543.86
201	25.00	23731.00	45.00	19999.50	25.00	33568.86
202	25.00	23756.00	45.00	20044.50	25.00	33593.86
203	25.00	23781.00	45.00	20089.50	25.00	33618.86
204	25.00	23806.00	45.00	20134.50	25.00	33643.86
205	25.00	23831.00	45.00	20179.50	25.00	33668.86
206	25.00	23856.00	45.00	20224.50	25.00	33693.86
207	25.00	23881.00	45.00	20269.50	25.00	33718.86
208	25.00	23906.00	45.00	20314.50	25.00	33743.86
209	25.00	23931.00	45.00	20359.50	25.00	33768.86
210	25.00	23956.00	45.00	20404.50	25.00	33793.86
211	25.00	23981.00	45.00	20449.50	25.00	33818.86
212	25.00	24006.00	45.00	20494.50	25.00	33843.86
213	25.00	24031.00	45.00	20539.50	25.00	33868.86
214	25.00	24056.00	45.00	20584.50	25.00	33893.86
215	25.00	24081.00	45.00	20629.50	25.00	33918.86
216	25.00	24106.00	45.00	20674.50	25.00	33943.86
217	25.00	24131.00	45.00	20719.50	25.00	33968.86
218	25.00	24156.00	45.00	20764.50	25.00	33993.86
219	25.00	24181.00	45.00	20809.50	25.00	34018.86
220	25.00	24206.00	45.00	20854.50	25.00	34043.86
221	25.00	24231.00	45.00	20899.50	25.00	34068.86
222	25.00	24256.00	45.00	20944.50	25.00	34093.86
223	25.00	24281.00	45.00	20989.50	25.00	34118.86
224	25.00	24306.00	45.00	21034.50	25.00	34143.86
225	25.00	24331.00	45.00	21079.50	25.00	34168.86
226	25.00	24356.00	45.00	21124.50	25.00	34193.86
227	25.00	24381.00	45.00	21169.50	25.00	34218.86
228	25.00	24406.00	45.00	21214.50	25.00	34243.86
229	25.00	24431.00	45.00	21259.50	25.00	34268.86
230	25.00	24456.00	45.00	21304.50	25.00	34293.86
231	25.00	24481.00	45.00	21349.50	25.00	34318.86
232	25.00	24506.00	45.00	21394.50	25.00	34343.86
233	25.00	24531.00	45.00	21439.50	25.00	34368.86
234	25.00	24556.00	45.00	21484.50	25.00	34393.86
235	25.00	24581.00	45.00	21529.50	25.00	34418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
236	25.00	24606.00	45.00	21574.50	25.00	34443.86
237	25.00	24631.00	45.00	21619.50	25.00	34468.86
238	25.00	24656.00	45.00	21664.50	25.00	34493.86
239	25.00	24681.00	45.00	21709.50	25.00	34518.86
240	25.00	24706.00	45.00	21754.50	25.00	34543.86
241	25.00	24731.00	45.00	21799.50	25.00	34568.86
242	25.00	24756.00	45.00	21844.50	25.00	34593.86
243	25.00	24781.00	45.00	21889.50	25.00	34618.86
244	25.00	24806.00	45.00	21934.50	25.00	34643.86
245	25.00	24831.00	45.00	21979.50	25.00	34668.86
246	25.00	24856.00	45.00	22024.50	25.00	34693.86
247	25.00	24881.00	45.00	22069.50	25.00	34718.86
248	25.00	24906.00	45.00	22114.50	25.00	34743.86
249	25.00	24931.00	45.00	22159.50	25.00	34768.86
250	25.00	24956.00	45.00	22204.50	25.00	34793.86
251	25.00	24981.00	45.00	22249.50	25.00	34818.86
252	25.00	25006.00	45.00	22294.50	25.00	34843.86
253	25.00	25031.00	45.00	22339.50	25.00	34868.86
254	25.00	25056.00	45.00	22384.50	25.00	34893.86
255	25.00	25081.00	45.00	22429.50	25.00	34918.86
256	25.00	25106.00	45.00	22474.50	25.00	34943.86
257	25.00	25131.00	45.00	22519.50	25.00	34968.86
258	25.00	25156.00	45.00	22564.50	25.00	34993.86
259	25.00	25181.00	45.00	22609.50	25.00	35018.86
260	25.00	25206.00	45.00	22654.50	25.00	35043.86
261	25.00	25231.00	45.00	22699.50	25.00	35068.86
262	25.00	25256.00	45.00	22744.50	25.00	35093.86
263	25.00	25281.00	45.00	22789.50	25.00	35118.86
264	25.00	25306.00	45.00	22834.50	25.00	35143.86
265	25.00	25331.00	45.00	22879.50	25.00	35168.86
266	25.00	25356.00	45.00	22924.50	25.00	35193.86
267	25.00	25381.00	45.00	22969.50	25.00	35218.86
268	25.00	25406.00	45.00	23014.50	25.00	35243.86
269	25.00	25431.00	45.00	23059.50	25.00	35268.86
270	25.00	25456.00	45.00	23104.50	25.00	35293.86
271	25.00	25481.00	45.00	23149.50	25.00	35318.86
272	25.00	25506.00	45.00	23194.50	25.00	35343.86
273	25.00	25531.00	45.00	23239.50	25.00	35368.86
274	25.00	25556.00	45.00	23284.50	25.00	35393.86
275	25.00	25581.00	45.00	23329.50	25.00	35418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
276	25.00	25606.00	45.00	23374.50	25.00	35443.86
277	25.00	25631.00	45.00	23419.50	25.00	35468.86
278	25.00	25656.00	45.00	23464.50	25.00	35493.86
279	25.00	25681.00	45.00	23509.50	25.00	35518.86
280	25.00	25706.00	45.00	23554.50	25.00	35543.86
281	25.00	25731.00	45.00	23599.50	25.00	35568.86
282	25.00	25756.00	45.00	23644.50	25.00	35593.86
283	25.00	25781.00	45.00	23689.50	25.00	35618.86
284	25.00	25806.00	45.00	23734.50	25.00	35643.86
285	25.00	25831.00	45.00	23779.50	25.00	35668.86
286	25.00	25856.00	45.00	23824.50	25.00	35693.86
287	25.00	25881.00	45.00	23869.50	25.00	35718.86
288	25.00	25906.00	45.00	23914.50	25.00	35743.86
289	25.00	25931.00	45.00	23959.50	25.00	35768.86
290	25.00	25956.00	45.00	24004.50	25.00	35793.86
291	25.00	25981.00	45.00	24049.50	25.00	35818.86
292	25.00	26006.00	45.00	24094.50	25.00	35843.86
293	25.00	26031.00	45.00	24139.50	25.00	35868.86
294	25.00	26056.00	45.00	24184.50	25.00	35893.86
295	25.00	26081.00	45.00	24229.50	25.00	35918.86
296	25.00	26106.00	45.00	24274.50	25.00	35943.86
297	25.00	26131.00	45.00	24319.50	25.00	35968.86
298	25.00	26156.00	45.00	24364.50	25.00	35993.86
299	25.00	26181.00	45.00	24409.50	25.00	36018.86
300	25.00	26206.00	45.00	24454.50	25.00	36043.86
301	25.00	26231.00	45.00	24499.50	25.00	36068.86
302	25.00	26256.00	45.00	24544.50	25.00	36093.86
303	25.00	26281.00	45.00	24589.50	25.00	36118.86
304	25.00	26306.00	45.00	24634.50	25.00	36143.86
305	25.00	26331.00	45.00	24679.50	25.00	36168.86
306	25.00	26356.00	45.00	24724.50	25.00	36193.86
307	25.00	26381.00	45.00	24769.50	25.00	36218.86
308	25.00	26406.00	45.00	24814.50	25.00	36243.86
309	25.00	26431.00	45.00	24859.50	25.00	36268.86
310	25.00	26456.00	45.00	24904.50	25.00	36293.86
311	25.00	26481.00	45.00	24949.50	25.00	36318.86
312	25.00	26506.00	45.00	24994.50	25.00	36343.86
313	25.00	26531.00	45.00	25039.50	25.00	36368.86
314	25.00	26556.00	45.00	25084.50	25.00	36393.86
315	25.00	26581.00	45.00	25129.50	25.00	36418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
316	25.00	26606.00	45.00	25174.50	25.00	36443.86
317	25.00	26631.00	45.00	25219.50	25.00	36468.86
318	25.00	26656.00	45.00	25264.50	25.00	36493.86
319	25.00	26681.00	45.00	25309.50	25.00	36518.86
320	25.00	26706.00	45.00	25354.50	25.00	36543.86
321	25.00	26731.00	45.00	25399.50	25.00	36568.86
322	25.00	26756.00	45.00	25444.50	25.00	36593.86
323	25.00	26781.00	45.00	25489.50	25.00	36618.86
324	25.00	26806.00	45.00	25534.50	25.00	36643.86
325	25.00	26831.00	45.00	25579.50	25.00	36668.86
326	25.00	26856.00	45.00	25624.50	25.00	36693.86
327	25.00	26881.00	45.00	25669.50	25.00	36718.86
328	25.00	26906.00	45.00	25714.50	25.00	36743.86
329	25.00	26931.00	45.00	25759.50	25.00	36768.86
330	25.00	26956.00	45.00	25804.50	25.00	36793.86
331	25.00	26981.00	45.00	25849.50	25.00	36818.86
332	25.00	27006.00	45.00	25894.50	25.00	36843.86
333	25.00	27031.00	45.00	25939.50	25.00	36868.86
334	25.00	27056.00	45.00	25984.50	25.00	36893.86
335	25.00	27081.00	45.00	26029.50	25.00	36918.86
336	25.00	27106.00	45.00	26074.50	25.00	36943.86
337	25.00	27131.00	45.00	26119.50	25.00	36968.86
338	25.00	27156.00	45.00	26164.50	25.00	36993.86
339	25.00	27181.00	45.00	26209.50	25.00	37018.86
340	25.00	27206.00	45.00	26254.50	25.00	37043.86
341	25.00	27231.00	45.00	26299.50	25.00	37068.86
342	25.00	27256.00	45.00	26344.50	25.00	37093.86
343	25.00	27281.00	45.00	26389.50	25.00	37118.86
344	25.00	27306.00	45.00	26434.50	25.00	37143.86
345	25.00	27331.00	45.00	26479.50	25.00	37168.86
346	25.00	27356.00	45.00	26524.50	25.00	37193.86
347	25.00	27381.00	45.00	26569.50	25.00	37218.86
348	25.00	27406.00	45.00	26614.50	25.00	37243.86
349	25.00	27431.00	45.00	26659.50	25.00	37268.86
350	25.00	27456.00	45.00	26704.50	25.00	37293.86
351	25.00	27481.00	45.00	26749.50	25.00	37318.86
352	25.00	27506.00	45.00	26794.50	25.00	37343.86
353	25.00	27531.00	45.00	26839.50	25.00	37368.86
354	25.00	27556.00	45.00	26884.50	25.00	37393.86
355	25.00	27581.00	45.00	26929.50	25.00	37418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
356	25.00	27606.00	45.00	26974.50	25.00	37443.86
357	25.00	27631.00	45.00	27019.50	25.00	37468.86
358	25.00	27656.00	45.00	27064.50	25.00	37493.86
359	25.00	27681.00	45.00	27109.50	25.00	37518.86
360	25.00	27706.00	45.00	27154.50	25.00	37543.86
361	25.00	27731.00	45.00	27199.50	25.00	37568.86
362	25.00	27756.00	45.00	27244.50	25.00	37593.86
363	25.00	27781.00	45.00	27289.50	25.00	37618.86
364	25.00	27806.00	45.00	27334.50	25.00	37643.86
365	25.00	27831.00	45.00	27379.50	25.00	37668.86
366	25.00	27856.00	45.00	27424.50	25.00	37693.86
367	25.00	27881.00	45.00	27469.50	25.00	37718.86
368	25.00	27906.00	45.00	27514.50	25.00	37743.86
369	25.00	27931.00	45.00	27559.50	25.00	37768.86
370	25.00	27956.00	45.00	27604.50	25.00	37793.86
371	25.00	27981.00	45.00	27649.50	25.00	37818.86
372	25.00	28006.00	45.00	27694.50	25.00	37843.86
373	25.00	28031.00	45.00	27739.50	25.00	37868.86
374	25.00	28056.00	45.00	27784.50	25.00	37893.86
375	25.00	28081.00	45.00	27829.50	25.00	37918.86
376	25.00	28106.00	45.00	27874.50	25.00	37943.86
377	25.00	28131.00	45.00	27919.50	25.00	37968.86
378	25.00	28156.00	45.00	27964.50	25.00	37993.86
379	25.00	28181.00	45.00	28009.50	25.00	38018.86
380	25.00	28206.00	45.00	28054.50	25.00	38043.86
381	25.00	28231.00	45.00	28099.50	25.00	38068.86
382	25.00	28256.00	45.00	28144.50	25.00	38093.86
383	25.00	28281.00	45.00	28189.50	25.00	38118.86
384	25.00	28306.00	45.00	28234.50	25.00	38143.86
385	25.00	28331.00	45.00	28279.50	25.00	38168.86
386	25.00	28356.00	45.00	28324.50	25.00	38193.86
387	25.00	28381.00	45.00	28369.50	25.00	38218.86
388	25.00	28406.00	45.00	28414.50	25.00	38243.86
389	25.00	28431.00	45.00	28459.50	25.00	38268.86
390	25.00	28456.00	45.00	28504.50	25.00	38293.86
391	25.00	28481.00	45.00	28549.50	25.00	38318.86
392	25.00	28506.00	45.00	28594.50	25.00	38343.86
393	25.00	28531.00	45.00	28639.50	25.00	38368.86
394	25.00	28556.00	45.00	28684.50	25.00	38393.86
395	25.00	28581.00	45.00	28729.50	25.00	38418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
396	25.00	28606.00	45.00	28774.50	25.00	38443.86
397	25.00	28631.00	45.00	28819.50	25.00	38468.86
398	25.00	28656.00	45.00	28864.50	25.00	38493.86
399	25.00	28681.00	45.00	28909.50	25.00	38518.86
400	25.00	28706.00	45.00	28954.50	25.00	38543.86
401	25.00	28731.00	45.00	28999.50	25.00	38568.86
402	25.00	28756.00	45.00	29044.50	25.00	38593.86
403	25.00	28781.00	45.00	29089.50	25.00	38618.86
404	25.00	28806.00	45.00	29134.50	25.00	38643.86
405	25.00	28831.00	45.00	29179.50	25.00	38668.86
406	25.00	28856.00	45.00	29224.50	25.00	38693.86
407	25.00	28881.00	45.00	29269.50	25.00	38718.86
408	25.00	28906.00	45.00	29314.50	25.00	38743.86
409	25.00	28931.00	45.00	29359.50	25.00	38768.86
410	25.00	28956.00	45.00	29404.50	25.00	38793.86
411	25.00	28981.00	45.00	29449.50	25.00	38818.86
412	25.00	29006.00	45.00	29494.50	25.00	38843.86
413	25.00	29031.00	45.00	29539.50	25.00	38868.86
414	25.00	29056.00	45.00	29584.50	25.00	38893.86
415	25.00	29081.00	45.00	29629.50	25.00	38918.86
416	25.00	29106.00	45.00	29674.50	25.00	38943.86
417	25.00	29131.00	45.00	29719.50	25.00	38968.86
418	25.00	29156.00	45.00	29764.50	25.00	38993.86
419	25.00	29181.00	45.00	29809.50	25.00	39018.86
420	25.00	29206.00	45.00	29854.50	25.00	39043.86
421	25.00	29231.00	45.00	29899.50	25.00	39068.86
422	25.00	29256.00	45.00	29944.50	25.00	39093.86
423	25.00	29281.00	45.00	29989.50	25.00	39118.86
424	25.00	29306.00	45.00	30034.50	25.00	39143.86
425	25.00	29331.00	45.00	30079.50	25.00	39168.86
426	25.00	29356.00	45.00	30124.50	25.00	39193.86
427	25.00	29381.00	45.00	30169.50	25.00	39218.86
428	25.00	29406.00	45.00	30214.50	25.00	39243.86
429	25.00	29431.00	45.00	30259.50	25.00	39268.86
430	25.00	29456.00	45.00	30304.50	25.00	39293.86
431	25.00	29481.00	45.00	30349.50	25.00	39318.86
432	25.00	29506.00	45.00	30394.50	25.00	39343.86
433	25.00	29531.00	45.00	30439.50	25.00	39368.86
434	25.00	29556.00	45.00	30484.50	25.00	39393.86
435	25.00	29581.00	45.00	30529.50	25.00	39418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
436	25.00	29606.00	45.00	30574.50	25.00	39443.86
437	25.00	29631.00	45.00	30619.50	25.00	39468.86
438	25.00	29656.00	45.00	30664.50	25.00	39493.86
439	25.00	29681.00	45.00	30709.50	25.00	39518.86
440	25.00	29706.00	45.00	30754.50	25.00	39543.86
441	25.00	29731.00	45.00	30799.50	25.00	39568.86
442	25.00	29756.00	45.00	30844.50	25.00	39593.86
443	25.00	29781.00	45.00	30889.50	25.00	39618.86
444	25.00	29806.00	45.00	30934.50	25.00	39643.86
445	25.00	29831.00	45.00	30979.50	25.00	39668.86
446	25.00	29856.00	45.00	31024.50	25.00	39693.86
447	25.00	29881.00	45.00	31069.50	25.00	39718.86
448	25.00	29906.00	45.00	31114.50	25.00	39743.86
449	25.00	29931.00	45.00	31159.50	25.00	39768.86
450	25.00	29956.00	45.00	31204.50	25.00	39793.86
451	25.00	29981.00	45.00	31249.50	25.00	39818.86
452	25.00	30006.00	45.00	31294.50	25.00	39843.86
453	25.00	30031.00	45.00	31339.50	25.00	39868.86
454	25.00	30056.00	45.00	31384.50	25.00	39893.86
455	25.00	30081.00	45.00	31429.50	25.00	39918.86
456	25.00	30106.00	45.00	31474.50	25.00	39943.86
457	25.00	30131.00	45.00	31519.50	25.00	39968.86
458	25.00	30156.00	45.00	31564.50	25.00	39993.86
459	25.00	30181.00	45.00	31609.50	25.00	40018.86
460	25.00	30206.00	45.00	31654.50	25.00	40043.86
461	25.00	30231.00	45.00	31699.50	25.00	40068.86
462	25.00	30256.00	45.00	31744.50	25.00	40093.86
463	25.00	30281.00	45.00	31789.50	25.00	40118.86
464	25.00	30306.00	45.00	31834.50	25.00	40143.86
465	25.00	30331.00	45.00	31879.50	25.00	40168.86
466	25.00	30356.00	45.00	31924.50	25.00	40193.86
467	25.00	30381.00	45.00	31969.50	25.00	40218.86
468	25.00	30406.00	45.00	32014.50	25.00	40243.86
469	25.00	30431.00	45.00	32059.50	25.00	40268.86
470	25.00	30456.00	45.00	32104.50	25.00	40293.86
471	25.00	30481.00	45.00	32149.50	25.00	40318.86
472	25.00	30506.00	45.00	32194.50	25.00	40343.86
473	25.00	30531.00	45.00	32239.50	25.00	40368.86
474	25.00	30556.00	45.00	32284.50	25.00	40393.86
475	25.00	30581.00	45.00	32329.50	25.00	40418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
476	25.00	30606.00	45.00	32374.50	25.00	40443.86
477	25.00	30631.00	45.00	32419.50	25.00	40468.86
478	25.00	30656.00	45.00	32464.50	25.00	40493.86
479	25.00	30681.00	45.00	32509.50	25.00	40518.86
480	25.00	30706.00	45.00	32554.50	25.00	40543.86
481	25.00	30731.00	45.00	32599.50	25.00	40568.86
482	25.00	30756.00	45.00	32644.50	25.00	40593.86
483	25.00	30781.00	45.00	32689.50	25.00	40618.86
484	25.00	30806.00	45.00	32734.50	25.00	40643.86
485	25.00	30831.00	45.00	32779.50	25.00	40668.86
486	25.00	30856.00	45.00	32824.50	25.00	40693.86
487	25.00	30881.00	45.00	32869.50	25.00	40718.86
488	25.00	30906.00	45.00	32914.50	25.00	40743.86
489	25.00	30931.00	45.00	32959.50	25.00	40768.86
490	25.00	30956.00	45.00	33004.50	25.00	40793.86
491	25.00	30981.00	45.00	33049.50	25.00	40818.86
492	25.00	31006.00	45.00	33094.50	25.00	40843.86
493	25.00	31031.00	45.00	33139.50	25.00	40868.86
494	25.00	31056.00	45.00	33184.50	25.00	40893.86
495	25.00	31081.00	45.00	33229.50	25.00	40918.86
496	25.00	31106.00	45.00	33274.50	25.00	40943.86
497	25.00	31131.00	45.00	33319.50	25.00	40968.86
498	25.00	31156.00	45.00	33364.50	25.00	40993.86
499	25.00	31181.00	45.00	33409.50	25.00	41018.86
500	25.00	31206.00	45.00	33454.50	25.00	41043.86
501	25.00	31231.00	45.00	33499.50	25.00	41068.86
502	25.00	31256.00	45.00	33544.50	25.00	41093.86
503	25.00	31281.00	45.00	33589.50	25.00	41118.86
504	25.00	31306.00	45.00	33634.50	25.00	41143.86
505	25.00	31331.00	45.00	33679.50	25.00	41168.86
506	25.00	31356.00	45.00	33724.50	25.00	41193.86
507	25.00	31381.00	45.00	33769.50	25.00	41218.86
508	25.00	31406.00	45.00	33814.50	25.00	41243.86
509	25.00	31431.00	45.00	33859.50	25.00	41268.86
510	25.00	31456.00	45.00	33904.50	25.00	41293.86
511	25.00	31481.00	45.00	33949.50	25.00	41318.86
512	25.00	31506.00	45.00	33994.50	25.00	41343.86
513	25.00	31531.00	45.00	34039.50	25.00	41368.86
514	25.00	31556.00	45.00	34084.50	25.00	41393.86
515	25.00	31581.00	45.00	34129.50	25.00	41418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
516	25.00	31606.00	45.00	34174.50	25.00	41443.86
517	25.00	31631.00	45.00	34219.50	25.00	41468.86
518	25.00	31656.00	45.00	34264.50	25.00	41493.86
519	25.00	31681.00	45.00	34309.50	25.00	41518.86
520	25.00	31706.00	45.00	34354.50	25.00	41543.86
521	25.00	31731.00	45.00	34399.50	25.00	41568.86
522	25.00	31756.00	45.00	34444.50	25.00	41593.86
523	25.00	31781.00	45.00	34489.50	25.00	41618.86
524	25.00	31806.00	45.00	34534.50	25.00	41643.86
525	25.00	31831.00	45.00	34579.50	25.00	41668.86
526	25.00	31856.00	45.00	34624.50	25.00	41693.86
527	25.00	31881.00	45.00	34669.50	25.00	41718.86
528	25.00	31906.00	45.00	34714.50	25.00	41743.86
529	25.00	31931.00	45.00	34759.50	25.00	41768.86
530	25.00	31956.00	45.00	34804.50	25.00	41793.86
531	25.00	31981.00	45.00	34849.50	25.00	41818.86
532	25.00	32006.00	45.00	34894.50	25.00	41843.86
533	25.00	32031.00	45.00	34939.50	25.00	41868.86
534	25.00	32056.00	45.00	34984.50	25.00	41893.86
535	25.00	32081.00	45.00	35029.50	25.00	41918.86
536	25.00	32106.00	45.00	35074.50	25.00	41943.86
537	25.00	32131.00	45.00	35119.50	25.00	41968.86
538	25.00	32156.00	45.00	35164.50	25.00	41993.86
539	25.00	32181.00	45.00	35209.50	25.00	42018.86
540	25.00	32206.00	45.00	35254.50	25.00	42043.86
541	25.00	32231.00	45.00	35299.50	25.00	42068.86
542	25.00	32256.00	45.00	35344.50	25.00	42093.86
543	25.00	32281.00	45.00	35389.50	25.00	42118.86
544	25.00	32306.00	45.00	35434.50	25.00	42143.86
545	25.00	32331.00	45.00	35479.50	25.00	42168.86
546	25.00	32356.00	45.00	35524.50	25.00	42193.86
547	25.00	32381.00	45.00	35569.50	25.00	42218.86
548	25.00	32406.00	45.00	35614.50	25.00	42243.86
549	25.00	32431.00	45.00	35659.50	25.00	42268.86
550	25.00	32456.00	45.00	35704.50	25.00	42293.86
551	25.00	32481.00	45.00	35749.50	25.00	42318.86
552	25.00	32506.00	45.00	35794.50	25.00	42343.86
553	25.00	32531.00	45.00	35839.50	25.00	42368.86
554	25.00	32556.00	45.00	35884.50	25.00	42393.86
555	25.00	32581.00	45.00	35929.50	25.00	42418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
556	25.00	32606.00	45.00	35974.50	25.00	42443.86
557	25.00	32631.00	45.00	36019.50	25.00	42468.86
558	25.00	32656.00	45.00	36064.50	25.00	42493.86
559	25.00	32681.00	45.00	36109.50	25.00	42518.86
560	25.00	32706.00	45.00	36154.50	25.00	42543.86
561	25.00	32731.00	45.00	36199.50	25.00	42568.86
562	25.00	32756.00	45.00	36244.50	25.00	42593.86
563	25.00	32781.00	45.00	36289.50	25.00	42618.86
564	25.00	32806.00	45.00	36334.50	25.00	42643.86
565	25.00	32831.00	45.00	36379.50	25.00	42668.86
566	25.00	32856.00	45.00	36424.50	25.00	42693.86
567	25.00	32881.00	45.00	36469.50	25.00	42718.86
568	25.00	32906.00	45.00	36514.50	25.00	42743.86
569	25.00	32931.00	45.00	36559.50	25.00	42768.86
570	25.00	32956.00	45.00	36604.50	25.00	42793.86
571	25.00	32981.00	45.00	36649.50	25.00	42818.86
572	25.00	33006.00	45.00	36694.50	25.00	42843.86
573	25.00	33031.00	45.00	36739.50	25.00	42868.86
574	25.00	33056.00	45.00	36784.50	25.00	42893.86
575	25.00	33081.00	45.00	36829.50	25.00	42918.86
576	25.00	33106.00	45.00	36874.50	25.00	42943.86
577	25.00	33131.00	45.00	36919.50	25.00	42968.86
578	25.00	33156.00	45.00	36964.50	25.00	42993.86
579	25.00	33181.00	45.00	37009.50	25.00	43018.86
580	25.00	33206.00	45.00	37054.50	25.00	43043.86
581	25.00	33231.00	45.00	37099.50	25.00	43068.86
582	25.00	33256.00	45.00	37144.50	25.00	43093.86
583	25.00	33281.00	45.00	37189.50	25.00	43118.86
584	25.00	33306.00	45.00	37234.50	25.00	43143.86
585	25.00	33331.00	45.00	37279.50	25.00	43168.86
586	25.00	33356.00	45.00	37324.50	25.00	43193.86
587	25.00	33381.00	45.00	37369.50	25.00	43218.86
588	25.00	33406.00	45.00	37414.50	25.00	43243.86
589	25.00	33431.00	45.00	37459.50	25.00	43268.86
590	25.00	33456.00	45.00	37504.50	25.00	43293.86
591	25.00	33481.00	45.00	37549.50	25.00	43318.86
592	25.00	33506.00	45.00	37594.50	25.00	43343.86
593	25.00	33531.00	45.00	37639.50	25.00	43368.86
594	25.00	33556.00	45.00	37684.50	25.00	43393.86
595	25.00	33581.00	45.00	37729.50	25.00	43418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
596	25.00	33606.00	45.00	37774.50	25.00	43443.86
597	25.00	33631.00	45.00	37819.50	25.00	43468.86
598	25.00	33656.00	45.00	37864.50	25.00	43493.86
599	25.00	33681.00	45.00	37909.50	25.00	43518.86
600	25.00	33706.00	45.00	37954.50	25.00	43543.86
601	25.00	33731.00	45.00	37999.50	25.00	43568.86
602	25.00	33756.00	45.00	38044.50	25.00	43593.86
603	25.00	33781.00	45.00	38089.50	25.00	43618.86
604	25.00	33806.00	45.00	38134.50	25.00	43643.86
605	25.00	33831.00	45.00	38179.50	25.00	43668.86
606	25.00	33856.00	45.00	38224.50	25.00	43693.86
607	25.00	33881.00	45.00	38269.50	25.00	43718.86
608	25.00	33906.00	45.00	38314.50	25.00	43743.86
609	25.00	33931.00	45.00	38359.50	25.00	43768.86
610	25.00	33956.00	45.00	38404.50	25.00	43793.86
611	25.00	33981.00	45.00	38449.50	25.00	43818.86
612	25.00	34006.00	45.00	38494.50	25.00	43843.86
613	25.00	34031.00	45.00	38539.50	25.00	43868.86
614	25.00	34056.00	45.00	38584.50	25.00	43893.86
615	25.00	34081.00	45.00	38629.50	25.00	43918.86
616	25.00	34106.00	45.00	38674.50	25.00	43943.86
617	25.00	34131.00	45.00	38719.50	25.00	43968.86
618	25.00	34156.00	45.00	38764.50	25.00	43993.86
619	25.00	34181.00	45.00	38809.50	25.00	44018.86
620	25.00	34206.00	45.00	38854.50	25.00	44043.86
621	25.00	34231.00	45.00	38899.50	25.00	44068.86
622	25.00	34256.00	45.00	38944.50	25.00	44093.86
623	25.00	34281.00	45.00	38989.50	25.00	44118.86
624	25.00	34306.00	45.00	39034.50	25.00	44143.86
625	25.00	34331.00	45.00	39079.50	25.00	44168.86
626	25.00	34356.00	45.00	39124.50	25.00	44193.86
627	25.00	34381.00	45.00	39169.50	25.00	44218.86
628	25.00	34406.00	45.00	39214.50	25.00	44243.86
629	25.00	34431.00	45.00	39259.50	25.00	44268.86
630	25.00	34456.00	45.00	39304.50	25.00	44293.86
631	25.00	34481.00	45.00	39349.50	25.00	44318.86
632	25.00	34506.00	45.00	39394.50	25.00	44343.86
633	25.00	34531.00	45.00	39439.50	25.00	44368.86
634	25.00	34556.00	45.00	39484.50	25.00	44393.86
635	25.00	34581.00	45.00	39529.50	25.00	44418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
636	25.00	34606.00	45.00	39574.50	25.00	44443.86
637	25.00	34631.00	45.00	39619.50	25.00	44468.86
638	25.00	34656.00	45.00	39664.50	25.00	44493.86
639	25.00	34681.00	45.00	39709.50	25.00	44518.86
640	25.00	34706.00	45.00	39754.50	25.00	44543.86
641	25.00	34731.00	45.00	39799.50	25.00	44568.86
642	25.00	34756.00	45.00	39844.50	25.00	44593.86
643	25.00	34781.00	45.00	39889.50	25.00	44618.86
644	25.00	34806.00	45.00	39934.50	25.00	44643.86
645	25.00	34831.00	45.00	39979.50	25.00	44668.86
646	25.00	34856.00	45.00	40024.50	25.00	44693.86
647	25.00	34881.00	45.00	40069.50	25.00	44718.86
648	25.00	34906.00	45.00	40114.50	25.00	44743.86
649	25.00	34931.00	45.00	40159.50	25.00	44768.86
650	25.00	34956.00	45.00	40204.50	25.00	44793.86
651	25.00	34981.00	45.00	40249.50	25.00	44818.86
652	25.00	35006.00	45.00	40294.50	25.00	44843.86
653	25.00	35031.00	45.00	40339.50	25.00	44868.86
654	25.00	35056.00	45.00	40384.50	25.00	44893.86
655	25.00	35081.00	45.00	40429.50	25.00	44918.86
656	25.00	35106.00	45.00	40474.50	25.00	44943.86
657	25.00	35131.00	45.00	40519.50	25.00	44968.86
658	25.00	35156.00	45.00	40564.50	25.00	44993.86
659	25.00	35181.00	45.00	40609.50	25.00	45018.86
660	25.00	35206.00	45.00	40654.50	25.00	45043.86
661	25.00	35231.00	45.00	40699.50	25.00	45068.86
662	25.00	35256.00	45.00	40744.50	25.00	45093.86
663	25.00	35281.00	45.00	40789.50	25.00	45118.86
664	25.00	35306.00	45.00	40834.50	25.00	45143.86
665	25.00	35331.00	45.00	40879.50	25.00	45168.86
666	25.00	35356.00	45.00	40924.50	25.00	45193.86
667	25.00	35381.00	45.00	40969.50	25.00	45218.86
668	25.00	35406.00	45.00	41014.50	25.00	45243.86
669	25.00	35431.00	45.00	41059.50	25.00	45268.86
670	25.00	35456.00	45.00	41104.50	25.00	45293.86
671	25.00	35481.00	45.00	41149.50	25.00	45318.86
672	25.00	35506.00	45.00	41194.50	25.00	45343.86
673	25.00	35531.00	45.00	41239.50	25.00	45368.86
674	25.00	35556.00	45.00	41284.50	25.00	45393.86
675	25.00	35581.00	45.00	41329.50	25.00	45418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
676	25.00	35606.00	45.00	41374.50	25.00	45443.86
677	25.00	35631.00	45.00	41419.50	25.00	45468.86
678	25.00	35656.00	45.00	41464.50	25.00	45493.86
679	25.00	35681.00	45.00	41509.50	25.00	45518.86
680	25.00	35706.00	45.00	41554.50	25.00	45543.86
681	25.00	35731.00	45.00	41599.50	25.00	45568.86
682	25.00	35756.00	45.00	41644.50	25.00	45593.86
683	25.00	35781.00	45.00	41689.50	25.00	45618.86
684	25.00	35806.00	45.00	41734.50	25.00	45643.86
685	25.00	35831.00	45.00	41779.50	25.00	45668.86
686	25.00	35856.00	45.00	41824.50	25.00	45693.86
687	25.00	35881.00	45.00	41869.50	25.00	45718.86
688	25.00	35906.00	45.00	41914.50	25.00	45743.86
689	25.00	35931.00	45.00	41959.50	25.00	45768.86
690	25.00	35956.00	45.00	42004.50	25.00	45793.86
691	25.00	35981.00	45.00	42049.50	25.00	45818.86
692	25.00	36006.00	45.00	42094.50	25.00	45843.86
693	25.00	36031.00	45.00	42139.50	25.00	45868.86
694	25.00	36056.00	45.00	42184.50	25.00	45893.86
695	25.00	36081.00	45.00	42229.50	25.00	45918.86
696	25.00	36106.00	45.00	42274.50	25.00	45943.86
697	25.00	36131.00	45.00	42319.50	25.00	45968.86
698	25.00	36156.00	45.00	42364.50	25.00	45993.86
699	25.00	36181.00	45.00	42409.50	25.00	46018.86
700	25.00	36206.00	45.00	42454.50	25.00	46043.86
701	25.00	36231.00	45.00	42499.50	25.00	46068.86
702	25.00	36256.00	45.00	42544.50	25.00	46093.86
703	25.00	36281.00	45.00	42589.50	25.00	46118.86
704	25.00	36306.00	45.00	42634.50	25.00	46143.86
705	25.00	36331.00	45.00	42679.50	25.00	46168.86
706	25.00	36356.00	45.00	42724.50	25.00	46193.86
707	25.00	36381.00	45.00	42769.50	25.00	46218.86
708	25.00	36406.00	45.00	42814.50	25.00	46243.86
709	25.00	36431.00	45.00	42859.50	25.00	46268.86
710	25.00	36456.00	45.00	42904.50	25.00	46293.86
711	25.00	36481.00	45.00	42949.50	25.00	46318.86
712	25.00	36506.00	45.00	42994.50	25.00	46343.86
713	25.00	36531.00	45.00	43039.50	25.00	46368.86
714	25.00	36556.00	45.00	43084.50	25.00	46393.86
715	25.00	36581.00	45.00	43129.50	25.00	46418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
716	25.00	36606.00	45.00	43174.50	25.00	46443.86
717	25.00	36631.00	45.00	43219.50	25.00	46468.86
718	25.00	36656.00	45.00	43264.50	25.00	46493.86
719	25.00	36681.00	45.00	43309.50	25.00	46518.86
720	25.00	36706.00	45.00	43354.50	25.00	46543.86
721	25.00	36731.00	45.00	43399.50	25.00	46568.86
722	25.00	36756.00	45.00	43444.50	25.00	46593.86
723	25.00	36781.00	45.00	43489.50	25.00	46618.86
724	25.00	36806.00	45.00	43534.50	25.00	46643.86
725	25.00	36831.00	45.00	43579.50	25.00	46668.86
726	25.00	36856.00	45.00	43624.50	25.00	46693.86
727	25.00	36881.00	45.00	43669.50	25.00	46718.86
728	25.00	36906.00	45.00	43714.50	25.00	46743.86
729	25.00	36931.00	45.00	43759.50	25.00	46768.86
730	25.00	36956.00	45.00	43804.50	25.00	46793.86
731	25.00	36981.00	45.00	43849.50	25.00	46818.86
732	25.00	37006.00	45.00	43894.50	25.00	46843.86
733	25.00	37031.00	45.00	43939.50	25.00	46868.86
734	25.00	37056.00	45.00	43984.50	25.00	46893.86
735	25.00	37081.00	45.00	44029.50	25.00	46918.86
736	25.00	37106.00	45.00	44074.50	25.00	46943.86
737	25.00	37131.00	45.00	44119.50	25.00	46968.86
738	25.00	37156.00	45.00	44164.50	25.00	46993.86
739	25.00	37181.00	45.00	44209.50	25.00	47018.86
740	25.00	37206.00	45.00	44254.50	25.00	47043.86
741	25.00	37231.00	45.00	44299.50	25.00	47068.86
742	25.00	37256.00	45.00	44344.50	25.00	47093.86
743	25.00	37281.00	45.00	44389.50	25.00	47118.86
744	25.00	37306.00	45.00	44434.50	25.00	47143.86
745	25.00	37331.00	45.00	44479.50	25.00	47168.86
746	25.00	37356.00	45.00	44524.50	25.00	47193.86
747	25.00	37381.00	45.00	44569.50	25.00	47218.86
748	25.00	37406.00	45.00	44614.50	25.00	47243.86
749	25.00	37431.00	45.00	44659.50	25.00	47268.86
750	25.00	37456.00	45.00	44704.50	25.00	47293.86
751	25.00	37481.00	45.00	44749.50	25.00	47318.86
752	25.00	37506.00	45.00	44794.50	25.00	47343.86
753	25.00	37531.00	45.00	44839.50	25.00	47368.86
754	25.00	37556.00	45.00	44884.50	25.00	47393.86
755	25.00	37581.00	45.00	44929.50	25.00	47418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
756	25.00	37606.00	45.00	44974.50	25.00	47443.86
757	25.00	37631.00	45.00	45019.50	25.00	47468.86
758	25.00	37656.00	45.00	45064.50	25.00	47493.86
759	25.00	37681.00	45.00	45109.50	25.00	47518.86
760	25.00	37706.00	45.00	45154.50	25.00	47543.86
761	25.00	37731.00	45.00	45199.50	25.00	47568.86
762	25.00	37756.00	45.00	45244.50	25.00	47593.86
763	25.00	37781.00	45.00	45289.50	25.00	47618.86
764	25.00	37806.00	45.00	45334.50	25.00	47643.86
765	25.00	37831.00	45.00	45379.50	25.00	47668.86
766	25.00	37856.00	45.00	45424.50	25.00	47693.86
767	25.00	37881.00	45.00	45469.50	25.00	47718.86
768	25.00	37906.00	45.00	45514.50	25.00	47743.86
769	25.00	37931.00	45.00	45559.50	25.00	47768.86
770	25.00	37956.00	45.00	45604.50	25.00	47793.86
771	25.00	37981.00	45.00	45649.50	25.00	47818.86
772	25.00	38006.00	45.00	45694.50	25.00	47843.86
773	25.00	38031.00	45.00	45739.50	25.00	47868.86
774	25.00	38056.00	45.00	45784.50	25.00	47893.86
775	25.00	38081.00	45.00	45829.50	25.00	47918.86
776	25.00	38106.00	45.00	45874.50	25.00	47943.86
777	25.00	38131.00	45.00	45919.50	25.00	47968.86
778	25.00	38156.00	45.00	45964.50	25.00	47993.86
779	25.00	38181.00	45.00	46009.50	25.00	48018.86
780	25.00	38206.00	45.00	46054.50	25.00	48043.86
781	25.00	38231.00	45.00	46099.50	25.00	48068.86
782	25.00	38256.00	45.00	46144.50	25.00	48093.86
783	25.00	38281.00	45.00	46189.50	25.00	48118.86
784	25.00	38306.00	45.00	46234.50	25.00	48143.86
785	25.00	38331.00	45.00	46279.50	25.00	48168.86
786	25.00	38356.00	45.00	46324.50	25.00	48193.86
787	25.00	38381.00	45.00	46369.50	25.00	48218.86
788	25.00	38406.00	45.00	46414.50	25.00	48243.86
789	25.00	38431.00	45.00	46459.50	25.00	48268.86
790	25.00	38456.00	45.00	46504.50	25.00	48293.86
791	25.00	38481.00	45.00	46549.50	25.00	48318.86
792	25.00	38506.00	45.00	46594.50	25.00	48343.86
793	25.00	38531.00	45.00	46639.50	25.00	48368.86
794	25.00	38556.00	45.00	46684.50	25.00	48393.86
795	25.00	38581.00	45.00	46729.50	25.00	48418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
796	25.00	38606.00	45.00	46774.50	25.00	48443.86
797	25.00	38631.00	45.00	46819.50	25.00	48468.86
798	25.00	38656.00	45.00	46864.50	25.00	48493.86
799	25.00	38681.00	45.00	46909.50	25.00	48518.86
800	25.00	38706.00	45.00	46954.50	25.00	48543.86
801	25.00	38731.00	45.00	46999.50	25.00	48568.86
802	25.00	38756.00	45.00	47044.50	25.00	48593.86
803	25.00	38781.00	45.00	47089.50	25.00	48618.86
804	25.00	38806.00	45.00	47134.50	25.00	48643.86
805	25.00	38831.00	45.00	47179.50	25.00	48668.86
806	25.00	38856.00	45.00	47224.50	25.00	48693.86
807	25.00	38881.00	45.00	47269.50	25.00	48718.86
808	25.00	38906.00	45.00	47314.50	25.00	48743.86
809	25.00	38931.00	45.00	47359.50	25.00	48768.86
810	25.00	38956.00	45.00	47404.50	25.00	48793.86
811	25.00	38981.00	45.00	47449.50	25.00	48818.86
812	25.00	39006.00	45.00	47494.50	25.00	48843.86
813	25.00	39031.00	45.00	47539.50	25.00	48868.86
814	25.00	39056.00	45.00	47584.50	25.00	48893.86
815	25.00	39081.00	45.00	47629.50	25.00	48918.86
816	25.00	39106.00	45.00	47674.50	25.00	48943.86
817	25.00	39131.00	45.00	47719.50	25.00	48968.86
818	25.00	39156.00	45.00	47764.50	25.00	48993.86
819	25.00	39181.00	45.00	47809.50	25.00	49018.86
820	25.00	39206.00	45.00	47854.50	25.00	49043.86
821	25.00	39231.00	45.00	47899.50	25.00	49068.86
822	25.00	39256.00	45.00	47944.50	25.00	49093.86
823	25.00	39281.00	45.00	47989.50	25.00	49118.86
824	25.00	39306.00	45.00	48034.50	25.00	49143.86
825	25.00	39331.00	45.00	48079.50	25.00	49168.86
826	25.00	39356.00	45.00	48124.50	25.00	49193.86
827	25.00	39381.00	45.00	48169.50	25.00	49218.86
828	25.00	39406.00	45.00	48214.50	25.00	49243.86
829	25.00	39431.00	45.00	48259.50	25.00	49268.86
830	25.00	39456.00	45.00	48304.50	25.00	49293.86
831	25.00	39481.00	45.00	48349.50	25.00	49318.86
832	25.00	39506.00	45.00	48394.50	25.00	49343.86
833	25.00	39531.00	45.00	48439.50	25.00	49368.86
834	25.00	39556.00	45.00	48484.50	25.00	49393.86
835	25.00	39581.00	45.00	48529.50	25.00	49418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
836	25.00	39606.00	45.00	48574.50	25.00	49443.86
837	25.00	39631.00	45.00	48619.50	25.00	49468.86
838	25.00	39656.00	45.00	48664.50	25.00	49493.86
839	25.00	39681.00	45.00	48709.50	25.00	49518.86
840	25.00	39706.00	45.00	48754.50	25.00	49543.86
841	25.00	39731.00	45.00	48799.50	25.00	49568.86
842	25.00	39756.00	45.00	48844.50	25.00	49593.86
843	25.00	39781.00	45.00	48889.50	25.00	49618.86
844	25.00	39806.00	45.00	48934.50	25.00	49643.86
845	25.00	39831.00	45.00	48979.50	25.00	49668.86
846	25.00	39856.00	45.00	49024.50	25.00	49693.86
847	25.00	39881.00	45.00	49069.50	25.00	49718.86
848	25.00	39906.00	45.00	49114.50	25.00	49743.86
849	25.00	39931.00	45.00	49159.50	25.00	49768.86
850	25.00	39956.00	45.00	49204.50	25.00	49793.86
851	25.00	39981.00	45.00	49249.50	25.00	49818.86
852	25.00	40006.00	45.00	49294.50	25.00	49843.86
853	25.00	40031.00	45.00	49339.50	25.00	49868.86
854	25.00	40056.00	45.00	49384.50	25.00	49893.86
855	25.00	40081.00	45.00	49429.50	25.00	49918.86
856	25.00	40106.00	45.00	49474.50	25.00	49943.86
857	25.00	40131.00	45.00	49519.50	25.00	49968.86
858	25.00	40156.00	45.00	49564.50	25.00	49993.86
859	25.00	40181.00	45.00	49609.50	25.00	50018.86
860	25.00	40206.00	45.00	49654.50	25.00	50043.86
861	25.00	40231.00	45.00	49699.50	25.00	50068.86
862	25.00	40256.00	45.00	49744.50	25.00	50093.86
863	25.00	40281.00	45.00	49789.50	25.00	50118.86
864	25.00	40306.00	45.00	49834.50	25.00	50143.86
865	25.00	40331.00	45.00	49879.50	25.00	50168.86
866	25.00	40356.00	45.00	49924.50	25.00	50193.86
867	25.00	40381.00	45.00	49969.50	25.00	50218.86
868	25.00	40406.00	45.00	50014.50	25.00	50243.86
869	25.00	40431.00	45.00	50059.50	25.00	50268.86
870	25.00	40456.00	45.00	50104.50	25.00	50293.86
871	25.00	40481.00	45.00	50149.50	25.00	50318.86
872	25.00	40506.00	45.00	50194.50	25.00	50343.86
873	25.00	40531.00	45.00	50239.50	25.00	50368.86
874	25.00	40556.00	45.00	50284.50	25.00	50393.86
875	25.00	40581.00	45.00	50329.50	25.00	50418.86

	GH1 w/tax credit		CH1		(GH1) w/o tax credit	
876	25.00	40606.00	45.00	50374.50	25.00	50443.86
877	25.00	40631.00	45.00	50419.50	25.00	50468.86
878	25.00	40656.00	45.00	50464.50	25.00	50493.86
879	25.00	40681.00	45.00	50509.50	25.00	50518.86
880	25.00	40706.00	45.00	50554.50	25.00	50543.86
881	25.00	40731.00	45.00	50599.50	25.00	50568.86
882	25.00	40756.00	45.00	50644.50	25.00	50593.86
883	25.00	40781.00	45.00	50689.50	25.00	50618.86
884	25.00	40806.00	45.00	50734.50	25.00	50643.86
885	25.00	40831.00	45.00	50779.50	25.00	50668.86
886	25.00	40856.00	45.00	50824.50	25.00	50693.86
887	25.00	40881.00	45.00	50869.50	25.00	50718.86

Case Study 2 Payback Period Calculation Using Excel

	GH2 with tax credit		CH2		GH2 w/o tax credit	
HVAC Initial Cost	42098.00		24509.50		42098.00	
Tax credit (30%)	12629.40					
Month		29468.60		24509.50		42098.00
1	130.00	29598.60	350.00	24859.50	130.00	42228.00
2	130.00	29728.60	350.00	25209.50	130.00	42358.00
3	130.00	29858.60	350.00	25559.50	130.00	42488.00
4	130.00	29988.60	350.00	25909.50	130.00	42618.00
5	130.00	30118.60	350.00	26259.50	130.00	42748.00
6	130.00	30248.60	350.00	26609.50	130.00	42878.00
7	130.00	30378.60	350.00	26959.50	130.00	43008.00
8	130.00	30508.60	350.00	27309.50	130.00	43138.00
9	130.00	30638.60	350.00	27659.50	130.00	43268.00
10	130.00	30768.60	350.00	28009.50	130.00	43398.00
11	130.00	30898.60	350.00	28359.50	130.00	43528.00
12	130.00	31028.60	350.00	28709.50	130.00	43658.00
13	130.00	31158.60	350.00	29059.50	130.00	43788.00
14	130.00	31288.60	350.00	29409.50	130.00	43918.00
15	130.00	31418.60	350.00	29759.50	130.00	44048.00
16	130.00	31548.60	350.00	30109.50	130.00	44178.00
17	130.00	31678.60	350.00	30459.50	130.00	44308.00
18	130.00	31808.60	350.00	30809.50	130.00	44438.00
19	130.00	31938.60	350.00	31159.50	130.00	44568.00
20	130.00	32068.60	350.00	31509.50	130.00	44698.00
21	130.00	32198.60	350.00	31859.50	130.00	44828.00

Table cont'd.

	GH2 with tax credit		CH2		GH2 w/o tax credit	
22	130.00	32328.60	350.00	32209.50	130.00	44958.00
23	130.00	32458.60	350.00	32559.50	130.00	45088.00
24	130.00	32588.60	350.00	32909.50	130.00	45218.00
25	130.00	32718.60	350.00	33259.50	130.00	45348.00
26	130.00	32848.60	350.00	33609.50	130.00	45478.00
27	130.00	32978.60	350.00	33959.50	130.00	45608.00
28	130.00	33108.60	350.00	34309.50	130.00	45738.00
29	130.00	33238.60	350.00	34659.50	130.00	45868.00
30	130.00	33368.60	350.00	35009.50	130.00	45998.00
31	130.00	33498.60	350.00	35359.50	130.00	46128.00
32	130.00	33628.60	350.00	35709.50	130.00	46258.00
33	130.00	33758.60	350.00	36059.50	130.00	46388.00
34	130.00	33888.60	350.00	36409.50	130.00	46518.00
35	130.00	34018.60	350.00	36759.50	130.00	46648.00
36	130.00	34148.60	350.00	37109.50	130.00	46778.00
37	130.00	34278.60	350.00	37459.50	130.00	46908.00
38	130.00	34408.60	350.00	37809.50	130.00	47038.00
39	130.00	34538.60	350.00	38159.50	130.00	47168.00
40	130.00	34668.60	350.00	38509.50	130.00	47298.00
41	130.00	34798.60	350.00	38859.50	130.00	47428.00
42	130.00	34928.60	350.00	39209.50	130.00	47558.00
43	130.00	35058.60	350.00	39559.50	130.00	47688.00
44	130.00	35188.60	350.00	39909.50	130.00	47818.00
45	130.00	35318.60	350.00	40259.50	130.00	47948.00
46	130.00	35448.60	350.00	40609.50	130.00	48078.00
47	130.00	35578.60	350.00	40959.50	130.00	48208.00
48	130.00	35708.60	350.00	41309.50	130.00	48338.00
49	130.00	35838.60	350.00	41659.50	130.00	48468.00
50	130.00	35968.60	350.00	42009.50	130.00	48598.00
51	130.00	36098.60	350.00	42359.50	130.00	48728.00
52	130.00	36228.60	350.00	42709.50	130.00	48858.00
53	130.00	36358.60	350.00	43059.50	130.00	48988.00
54	130.00	36488.60	350.00	43409.50	130.00	49118.00
55	130.00	36618.60	350.00	43759.50	130.00	49248.00
56	130.00	36748.60	350.00	44109.50	130.00	49378.00
57	130.00	36878.60	350.00	44459.50	130.00	49508.00
58	130.00	37008.60	350.00	44809.50	130.00	49638.00
59	130.00	37138.60	350.00	45159.50	130.00	49768.00
60	130.00	37268.60	350.00	45509.50	130.00	49898.00
61	130.00	37398.60	350.00	45859.50	130.00	50028.00

	GH2 with tax credit		CH2		GH2 w/o tax credit	
62	130.00	37528.60	350.00	46209.50	130.00	50158.00
63	130.00	37658.60	350.00	46559.50	130.00	50288.00
64	130.00	37788.60	350.00	46909.50	130.00	50418.00
65	130.00	37918.60	350.00	47259.50	130.00	50548.00
66	130.00	38048.60	350.00	47609.50	130.00	50678.00
67	130.00	38178.60	350.00	47959.50	130.00	50808.00
68	130.00	38308.60	350.00	48309.50	130.00	50938.00
69	130.00	38438.60	350.00	48659.50	130.00	51068.00
70	130.00	38568.60	350.00	49009.50	130.00	51198.00
71	130.00	38698.60	350.00	49359.50	130.00	51328.00
72	130.00	38828.60	350.00	49709.50	130.00	51458.00
73	130.00	38958.60	350.00	50059.50	130.00	51588.00
74	130.00	39088.60	350.00	50409.50	130.00	51718.00
75	130.00	39218.60	350.00	50759.50	130.00	51848.00
76	130.00	39348.60	350.00	51109.50	130.00	51978.00
77	130.00	39478.60	350.00	51459.50	130.00	52108.00
78	130.00	39608.60	350.00	51809.50	130.00	52238.00
79	130.00	39738.60	350.00	52159.50	130.00	52368.00
80	130.00	39868.60	350.00	52509.50	130.00	52498.00
81	130.00	39998.60	350.00	52859.50	130.00	52628.00
82	130.00	40128.60	350.00	53209.50	130.00	52758.00
83	130.00	40258.60	350.00	53559.50	130.00	52888.00
84	130.00	40388.60	350.00	53909.50	130.00	53018.00
85	130.00	40518.60	350.00	54259.50	130.00	53148.00
86	130.00	40648.60	350.00	54609.50	130.00	53278.00
87	130.00	40778.60	350.00	54959.50	130.00	53408.00
88	130.00	40908.60	350.00	55309.50	130.00	53538.00
89	130.00	41038.60	350.00	55659.50	130.00	53668.00
90	130.00	41168.60	350.00	56009.50	130.00	53798.00
91	130.00	41298.60	350.00	56359.50	130.00	53928.00
92	130.00	41428.60	350.00	56709.50	130.00	54058.00
93	130.00	41558.60	350.00	57059.50	130.00	54188.00
94	130.00	41688.60	350.00	57409.50	130.00	54318.00
95	130.00	41818.60	350.00	57759.50	130.00	54448.00
96	130.00	41948.60	350.00	58109.50	130.00	54578.00
97	130.00	42078.60	350.00	58459.50	130.00	54708.00
98	130.00	42208.60	350.00	58809.50	130.00	54838.00
99	130.00	42338.60	350.00	59159.50	130.00	54968.00
100	130.00	42468.60	350.00	59509.50	130.00	55098.00

Case Study 3 Payback Period Calculation Using Excel

	GH3 with tax credit		CH3		GH3 w/o tax credit	
HVAC Initial Cost	17013.00			9765.00		17013.00
Tax credit (30%)	5103.90					
Month		11909.10		9765.00		17013.00
1	70.00	11979.10	120.00	9885.00	70.00	17083.00
2	70.00	12049.10	120.00	10005.00	70.00	17153.00
3	70.00	12119.10	120.00	10125.00	70.00	17223.00
4	70.00	12189.10	120.00	10245.00	70.00	17293.00
5	70.00	12259.10	120.00	10365.00	70.00	17363.00
6	70.00	12329.10	120.00	10485.00	70.00	17433.00
7	70.00	12399.10	120.00	10605.00	70.00	17503.00
8	70.00	12469.10	120.00	10725.00	70.00	17573.00
9	70.00	12539.10	120.00	10845.00	70.00	17643.00
10	70.00	12609.10	120.00	10965.00	70.00	17713.00
11	70.00	12679.10	120.00	11085.00	70.00	17783.00
12	70.00	12749.10	120.00	11205.00	70.00	17853.00
13	70.00	12819.10	120.00	11325.00	70.00	17923.00
14	70.00	12889.10	120.00	11445.00	70.00	17993.00
15	70.00	12959.10	120.00	11565.00	70.00	18063.00
16	70.00	13029.10	120.00	11685.00	70.00	18133.00
17	70.00	13099.10	120.00	11805.00	70.00	18203.00
18	70.00	13169.10	120.00	11925.00	70.00	18273.00
19	70.00	13239.10	120.00	12045.00	70.00	18343.00
20	70.00	13309.10	120.00	12165.00	70.00	18413.00
21	70.00	13379.10	120.00	12285.00	70.00	18483.00
22	70.00	13449.10	120.00	12405.00	70.00	18553.00
23	70.00	13519.10	120.00	12525.00	70.00	18623.00
24	70.00	13589.10	120.00	12645.00	70.00	18693.00
25	70.00	13659.10	120.00	12765.00	70.00	18763.00
26	70.00	13729.10	120.00	12885.00	70.00	18833.00
27	70.00	13799.10	120.00	13005.00	70.00	18903.00
28	70.00	13869.10	120.00	13125.00	70.00	18973.00
29	70.00	13939.10	120.00	13245.00	70.00	19043.00
30	70.00	14009.10	120.00	13365.00	70.00	19113.00
31	70.00	14079.10	120.00	13485.00	70.00	19183.00
32	70.00	14149.10	120.00	13605.00	70.00	19253.00
33	70.00	14219.10	120.00	13725.00	70.00	19323.00
34	70.00	14289.10	120.00	13845.00	70.00	19393.00
35	70.00	14359.10	120.00	13965.00	70.00	19463.00

Table cont'd.

	GH3 with tax credit		CH3		GH3 w/o tax credit	
36	70.00	14429.10	120.00	14085.00	70.00	19533.00
37	70.00	14499.10	120.00	14205.00	70.00	19603.00
38	70.00	14569.10	120.00	14325.00	70.00	19673.00
39	70.00	14639.10	120.00	14445.00	70.00	19743.00
40	70.00	14709.10	120.00	14565.00	70.00	19813.00
41	70.00	14779.10	120.00	14685.00	70.00	19883.00
42	70.00	14849.10	120.00	14805.00	70.00	19953.00
43	70.00	14919.10	120.00	14925.00	70.00	20023.00
44	70.00	14989.10	120.00	15045.00	70.00	20093.00
45	70.00	15059.10	120.00	15165.00	70.00	20163.00
46	70.00	15129.10	120.00	15285.00	70.00	20233.00
47	70.00	15199.10	120.00	15405.00	70.00	20303.00
48	70.00	15269.10	120.00	15525.00	70.00	20373.00
49	70.00	15339.10	120.00	15645.00	70.00	20443.00
50	70.00	15409.10	120.00	15765.00	70.00	20513.00
51	70.00	15479.10	120.00	15885.00	70.00	20583.00
52	70.00	15549.10	120.00	16005.00	70.00	20653.00
53	70.00	15619.10	120.00	16125.00	70.00	20723.00
54	70.00	15689.10	120.00	16245.00	70.00	20793.00
55	70.00	15759.10	120.00	16365.00	70.00	20863.00
56	70.00	15829.10	120.00	16485.00	70.00	20933.00
57	70.00	15899.10	120.00	16605.00	70.00	21003.00
58	70.00	15969.10	120.00	16725.00	70.00	21073.00
59	70.00	16039.10	120.00	16845.00	70.00	21143.00
60	70.00	16109.10	120.00	16965.00	70.00	21213.00
61	70.00	16179.10	120.00	17085.00	70.00	21283.00
62	70.00	16249.10	120.00	17205.00	70.00	21353.00
63	70.00	16319.10	120.00	17325.00	70.00	21423.00
64	70.00	16389.10	120.00	17445.00	70.00	21493.00
65	70.00	16459.10	120.00	17565.00	70.00	21563.00
66	70.00	16529.10	120.00	17685.00	70.00	21633.00
67	70.00	16599.10	120.00	17805.00	70.00	21703.00
68	70.00	16669.10	120.00	17925.00	70.00	21773.00
69	70.00	16739.10	120.00	18045.00	70.00	21843.00
70	70.00	16809.10	120.00	18165.00	70.00	21913.00
71	70.00	16879.10	120.00	18285.00	70.00	21983.00
72	70.00	16949.10	120.00	18405.00	70.00	22053.00
73	70.00	17019.10	120.00	18525.00	70.00	22123.00
74	70.00	17089.10	120.00	18645.00	70.00	22193.00
75	70.00	17159.10	120.00	18765.00	70.00	22263.00

	GH3 with tax credit		CH3		GH3 w/o tax credit	
76	70.00	17229.10	120.00	18885.00	70.00	22333.00
77	70.00	17299.10	120.00	19005.00	70.00	22403.00
78	70.00	17369.10	120.00	19125.00	70.00	22473.00
79	70.00	17439.10	120.00	19245.00	70.00	22543.00
80	70.00	17509.10	120.00	19365.00	70.00	22613.00
81	70.00	17579.10	120.00	19485.00	70.00	22683.00
82	70.00	17649.10	120.00	19605.00	70.00	22753.00
83	70.00	17719.10	120.00	19725.00	70.00	22823.00
84	70.00	17789.10	120.00	19845.00	70.00	22893.00
85	70.00	17859.10	120.00	19965.00	70.00	22963.00
86	70.00	17929.10	120.00	20085.00	70.00	23033.00
87	70.00	17999.10	120.00	20205.00	70.00	23103.00
88	70.00	18069.10	120.00	20325.00	70.00	23173.00
89	70.00	18139.10	120.00	20445.00	70.00	23243.00
90	70.00	18209.10	120.00	20565.00	70.00	23313.00
91	70.00	18279.10	120.00	20685.00	70.00	23383.00
92	70.00	18349.10	120.00	20805.00	70.00	23453.00
93	70.00	18419.10	120.00	20925.00	70.00	23523.00
94	70.00	18489.10	120.00	21045.00	70.00	23593.00
95	70.00	18559.10	120.00	21165.00	70.00	23663.00
96	70.00	18629.10	120.00	21285.00	70.00	23733.00
97	70.00	18699.10	120.00	21405.00	70.00	23803.00
98	70.00	18769.10	120.00	21525.00	70.00	23873.00
99	70.00	18839.10	120.00	21645.00	70.00	23943.00
100	70.00	18909.10	120.00	21765.00	70.00	24013.00
101	70.00	18979.10	120.00	21885.00	70.00	24083.00
102	70.00	19049.10	120.00	22005.00	70.00	24153.00
103	70.00	19119.10	120.00	22125.00	70.00	24223.00
104	70.00	19189.10	120.00	22245.00	70.00	24293.00
105	70.00	19259.10	120.00	22365.00	70.00	24363.00
106	70.00	19329.10	120.00	22485.00	70.00	24433.00
107	70.00	19399.10	120.00	22605.00	70.00	24503.00
108	70.00	19469.10	120.00	22725.00	70.00	24573.00
109	70.00	19539.10	120.00	22845.00	70.00	24643.00
110	70.00	19609.10	120.00	22965.00	70.00	24713.00
111	70.00	19679.10	120.00	23085.00	70.00	24783.00
112	70.00	19749.10	120.00	23205.00	70.00	24853.00
113	70.00	19819.10	120.00	23325.00	70.00	24923.00
114	70.00	19889.10	120.00	23445.00	70.00	24993.00
115	70.00	19959.10	120.00	23565.00	70.00	25063.00

	GH3 with tax credit		CH3		GH3 w/o tax credit	
116	70.00	20029.10	120.00	23685.00	70.00	25133.00
117	70.00	20099.10	120.00	23805.00	70.00	25203.00
118	70.00	20169.10	120.00	23925.00	70.00	25273.00
119	70.00	20239.10	120.00	24045.00	70.00	25343.00
120	70.00	20309.10	120.00	24165.00	70.00	25413.00
121	70.00	20379.10	120.00	24285.00	70.00	25483.00
122	70.00	20449.10	120.00	24405.00	70.00	25553.00
123	70.00	20519.10	120.00	24525.00	70.00	25623.00
124	70.00	20589.10	120.00	24645.00	70.00	25693.00
125	70.00	20659.10	120.00	24765.00	70.00	25763.00
126	70.00	20729.10	120.00	24885.00	70.00	25833.00
127	70.00	20799.10	120.00	25005.00	70.00	25903.00
128	70.00	20869.10	120.00	25125.00	70.00	25973.00
129	70.00	20939.10	120.00	25245.00	70.00	26043.00
130	70.00	21009.10	120.00	25365.00	70.00	26113.00
131	70.00	21079.10	120.00	25485.00	70.00	26183.00
132	70.00	21149.10	120.00	25605.00	70.00	26253.00
133	70.00	21219.10	120.00	25725.00	70.00	26323.00
134	70.00	21289.10	120.00	25845.00	70.00	26393.00
135	70.00	21359.10	120.00	25965.00	70.00	26463.00
136	70.00	21429.10	120.00	26085.00	70.00	26533.00
137	70.00	21499.10	120.00	26205.00	70.00	26603.00
138	70.00	21569.10	120.00	26325.00	70.00	26673.00
139	70.00	21639.10	120.00	26445.00	70.00	26743.00
140	70.00	21709.10	120.00	26565.00	70.00	26813.00
141	70.00	21779.10	120.00	26685.00	70.00	26883.00
142	70.00	21849.10	120.00	26805.00	70.00	26953.00
143	70.00	21919.10	120.00	26925.00	70.00	27023.00
144	70.00	21989.10	120.00	27045.00	70.00	27093.00
145	70.00	22059.10	120.00	27165.00	70.00	27163.00
146	70.00	22129.10	120.00	27285.00	70.00	27233.00
147	70.00	22199.10	120.00	27405.00	70.00	27303.00
148	70.00	22269.10	120.00	27525.00	70.00	27373.00
149	70.00	22339.10	120.00	27645.00	70.00	27443.00
150	70.00	22409.10	120.00	27765.00	70.00	27513.00
151	70.00	22479.10	120.00	27885.00	70.00	27583.00
152	70.00	22549.10	120.00	28005.00	70.00	27653.00
153	70.00	22619.10	120.00	28125.00	70.00	27723.00
154	70.00	22689.10	120.00	28245.00	70.00	27793.00
155	70.00	22759.10	120.00	28365.00	70.00	27863.00

VITA

Claudia de Lourdes Duran Tapia was born and raised in Guayaquil-Ecuador. In 2013 she transferred to the University of New Orleans to complete her Bachelor's degree in Mechanical Engineering. She decided to pursue higher education and was accepted into The Bert S. Turner Department of Construction Management at Louisiana State University. During her years as a graduate student she has conducted research in geothermal heat pumps. She anticipates graduating with her Master degree in August 2017. She plans to apply her knowledge and gain professional experience by working in the construction industry or any engineering field related to her interests, in particular energy efficient technologies and systems for building facilities.