Energy Research and Development Division
FINAL PROJECT REPORT

ASSESSMENT OF CALIFORNIA'S LOW TEMPERATURE GEOTHERMAL RESOURCES: GEOTHERMAL HEAT PUMP EFFICIENCIES BY REGION

Evaluation of Geothermal Heat Pump System Use in California

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PREFACE

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Assessment of California's Low Temperature Geothermal Resources: Geothermal Heat Pump Efficiencies by Region is the final report for the Assessment of California's Low Temperature Geothermal Resources: Geothermal Heat Pump Efficiencies by Region project (contract number 500-08-017) conducted by California Energy Commission. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

California has a broad inventory of geothermal resources. High temperature geothermal systems are well recognized and have been an important part of California's renewable energy portfolio for many years. The low temperature resource, however, has remained inadequately characterized and developed, especially the technology that can be used for heating and cooling homes. This project evaluated the potential impacts of using geothermal heat pump systems in residential buildings. This study developed a residential building standard, based on United States census data, and used this standard to compute heating and cooling loads in the state's 16 distinct climate zones. Commercially available software was then used to design geothermal heat pump systems for each climate zone based on the electricity load calculations. The impacts on energy use by climate zone and on emissions of carbon dioxide, nitrogen oxides and sulfur dioxides were evaluated as well as natural gas displacement. The results showed that significant reductions in energy and natural gas demand and emissions would occur with geothermal heat pumps in 15 of the 16 climate zones. The energy use savings and emissions reductions (between about 20 and 70 percent) indicated that deploying these highly efficient systems could dramatically reduce energy consumption and atmospheric emissions statewide.

Keywords: California Energy Commission, geothermal heat pumps, heating, cooling, residential, energy use, emissions, climate zones

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EXECUTIVE SUMMARY

Introduction

Geothermal resources in California are diverse in character and distributed and the state possesses the nation's largest high temperature geothermal resource base. California also can maximize its low temperature geothermal resources which can be used by geothermal heat pump (GHP) systems to heat and cool building spaces. Such systems are among the most efficient and cost-effective means for conditioning interior air and use 25 percent to 50 percent less electricity than conventional heating and cooling systems. Minimal progress, however, has been made using GHP systems due to two factors: 1) The absence of an assessment that measures the applicability of GHP systems to California's diverse geology and climate zones; and 2) Insufficient analysis of the benefits these systems could provide to help California comply with a Renewables Performance Standard (RPS) and Assembly Bill 32 (AB 32), which mandates reductions in greenhouse gas (GHG) emissions.

Project Purpose

This project assessed applying GHP systems to California's geology and climate zones and to analyze the potential for these systems to help California meets its RPS and GHG emission reduction goals.

Project Results

GHP systems are some of the most efficient ways to heat and cool buildings. These systems rely on transferring heat from one thermal reservoir to another (this technology is well developed and refined) rather than generating heat through combustion such as heating with natural gas or electricity from fossil fuels using technologies that are inherently less efficient. Heat transfer in GHP systems uses a liquid-filled pipe loop in which the fluid is the heat transfer agent. Heat can be readily and efficiently moved back and forth between the building space and the subsurface by circulating the fluid through bore holes in the ground and then through a heat exchanger in the building. GHP systems have efficiencies for space heating that are three to five times that of conventional heating, ventilation and air conditioning (HVAC) equipment. The efficiency of these systems is due, in part, to subsurface, at depths of 50 to several hundred feet, maintains a constant temperature between 45 degrees Fahrenheit (°F) and 55°F. This is an ideal temperature range for building heating and cooling.

Designing geothermal heat pump systems requires knowledge of the actual subsurface temperature, the thermal conductivity and diffusivity of the subsurface rock units and the heating and cooling demand for the building. California is geologically diverse, with a complex array of rock types scattered throughout the state. These local geological characteristics must be taken into account for any specific location as well as the climatic characteristics of a site, since heating and cooling loads are direct reflection of local climate. California has 16 recognized climate zones.

A residential building standard was developed based on United States census data and used as a standard for computing heating and cooling loads in the state's distinct climate zones.

Commercially available software was used to design the heating and cooling loads for the respective climate zones.

The GHP loop design for the building representing each climate zones was accomplished with commercially available software (the GLD Premium design package). Design calculations were used as a range of thermal conductivity/diffusivity values rather than for a specific and assumed thermal conductivity/diffusivity set because of the diverse and complex geology within each climate zone. This allowed more rigorous and general comparisons and evaluation for the climate zones.

The impacts on energy use as compared to natural gas (heating) and the current California electric portfolio by climate zone were evaluated, as well as the impact on emissions of carbon dioxide (CO_2), nitrogen oxides (NOx) and sulfur dioxides (SO_2). The results showed that significant reductions (20 and 70 percent) in energy demand and emissions would occur with geothermal heat pumps in 15 of the 16 climate zones. The total electricity used in the state for conditioning building spaces could be reduced, decreasing the amount of electricity generated, and helping meet RPS goals. Installing more GHP systems will help reduce GHG emissions

Project Benefits

This project demonstrated that geothermal heat pump systems have the potential to significantly decrease electricity consumption while also reducing the costs of heating and cooling homes and commercial building spaces. The reduced energy consumption also directly reduces GHG emissions associated with power generation because of the decrease in electrical demand.

CHAPTER 1: Introduction

Using low temperature geothermal resources in California has a long history, and has included spas, greenhouses, aquaculture, district heating systems and geothermal heat pump systems (Witkin et al., 1979; Dellinger and Cooper, 1990; Bohm, 1995; Rafferty, 1999; Miller, 2002; Hodgson, 2003; OIT, 2003; CEC, 2005). Although evaluating California's high temperature resources, successfully used for power generation, has been the focus of numerous assessments (see Gawell, 2006 and Williams et al., 2008), work to thoroughly evaluate the importance of the low temperature resource as it relates to geothermal heat pump systems has been lacking. This study is the first systematic analysis of the potential for geothermal heat pump use in the state.

Geothermal heat pump systems (also known as ground source heat pumps, water source heat pumps, ground-coupled heat pumps or geoexchange systems) are used for space heating and cooling. Such systems are among the most efficient and cost-effective means for conditioning interior air. According to the Energy Efficiency and Renewable Energy (EERE) Office of the Department of Energy, geothermal heat pump systems use 25 percent to 50 percent less electricity than conventional heating and cooling systems (http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12660).

The U.S. Environmental Protection Agency (EPA) noted that geothermal heat pumps consume 44 percent less energy than air-source heat pump systems and 72 percent less energy than standard electric resistance heating equipment. Geothermal heat pump systems have the potential to significantly reduce electricity consumption while also reducing the costs of heating and cooling homes and commercial building spaces. The reduced energy consumption also directly reduces emissions associated with power generation, leading to lower GHG emissions and reduced atmospheric pollutants.

Despite their energy, economic and environmental benefits, installing geothermal heat pump systems in California has declined. According to the Energy Information Agency (EIA), in 2009, the capacity of geothermal heat pumps shipped to California was 6,998 tons, down from 9,522 tons in 2008 (http://www.eia.gov/cneaf/solar.renewables/page/heatpumps/heatpumps.html; Table 4.6). The total capacity (in tons) of heat pumps shipped within the U.S. in 2009 was 338,689 tons, indicating that California accounted for less than 2.1 percent of the total capacity shipped, or 19 out of the 50 states in geothermal heat pump use. These systems appear to be deployable in most settings, since successful installations of geothermal heat pump systems have been accomplished in climate zones across the United States (FEMP, 2003).

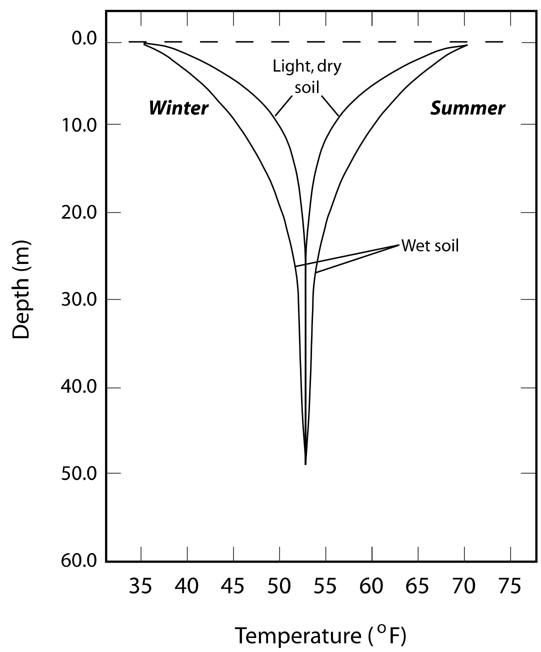
This study considers the characteristics of geothermal heat pump systems that could be deployed in California's 16 climate zones and concludes that significantly expanding these systems in the state is technically and environmentally justified. Although the economic benefits were not directly assessed in this study, the reduction in energy use accompanying geothermal heat pump installations are likely to result in major heating and cooling cost reductions. Using geothermal heat pump systems could substantially contribute to California achieving its Assembly Bill 32 (2006; Global Warming Solutions Act of 2006) mandated Greenhouse Gas Emission reduction goals, while simultaneously reducing overall electrical demand and complementing renewable energy production to achieve Renewable Portfolio Standard RPS goals while saving ratepayers money.

1.1 How Geothermal Heat Pump Systems Work

Geothermal heat pumps are high efficiency systems that transfer heat from the interior of a building to the subsurface or from the subsurface to the interior. These systems rely on the fact that temperatures in the subsurface remain relatively constant and are usually between ~50^{o}F and ~60^{o}F (~10^{o}C and ~16^{o}C) year round. This constant temperature falls between the high temperatures that occur in summer months when interior air cooling is needed (exterior temperatures exceed ~80^{o}F) and cold temperatures during winter months when interior air heating is necessary (exterior temperatures are less than ~50^{o}F). These circumstances allow heat to be removed from building interiors during summer months and deposited in the subsurface, while during winter months, subsurface heat can be extracted and transferred to building interiors.

The nearly constant temperatures in the subsurface are the result of the interactions between several processes. The ground surface temperature varies significantly by season, weather and time of day. These variations reflect the short-term effect of fluctuating solar energy deposition from solar exposure (insolation), soil transpiration, precipitation, infiltration and vegetation. At tens of feet in depth this variability is dramatically reduced through physical processes that diffuse and retard transmission and radiation of thermal energy. In addition, there is a constant flux of thermal energy from earth's interior toward the surface. This flux results in a geothermal gradient in which the subsurface temperature tends to approach a near-constant value with depth. The interaction of these combined processes varies from place to place, but the overall effect is that at some depth, the temperature in any particular location is nearly constant (Figure 1).

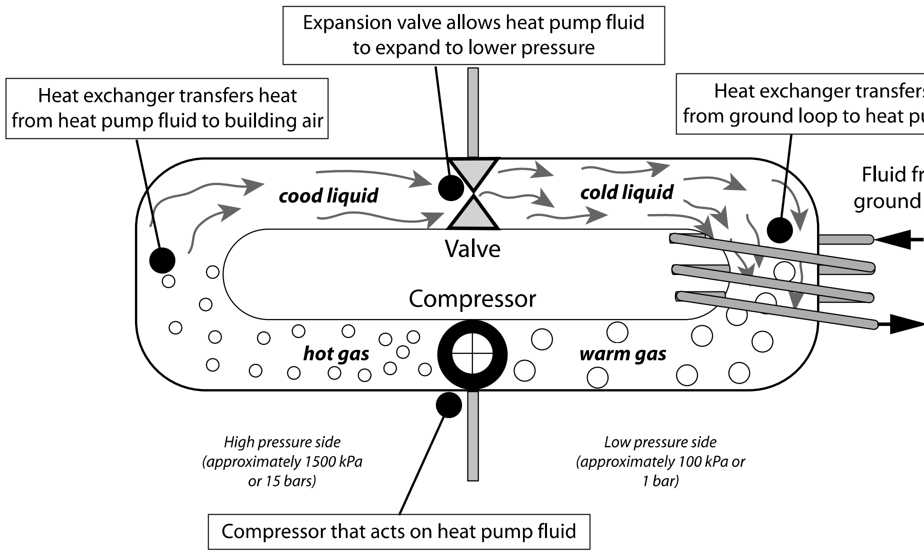
Figure 1: Idealized Subsurface Temperature Profile



Temperature is indicated as a function of depth, season and soil type (modified from Glassley, 2010).

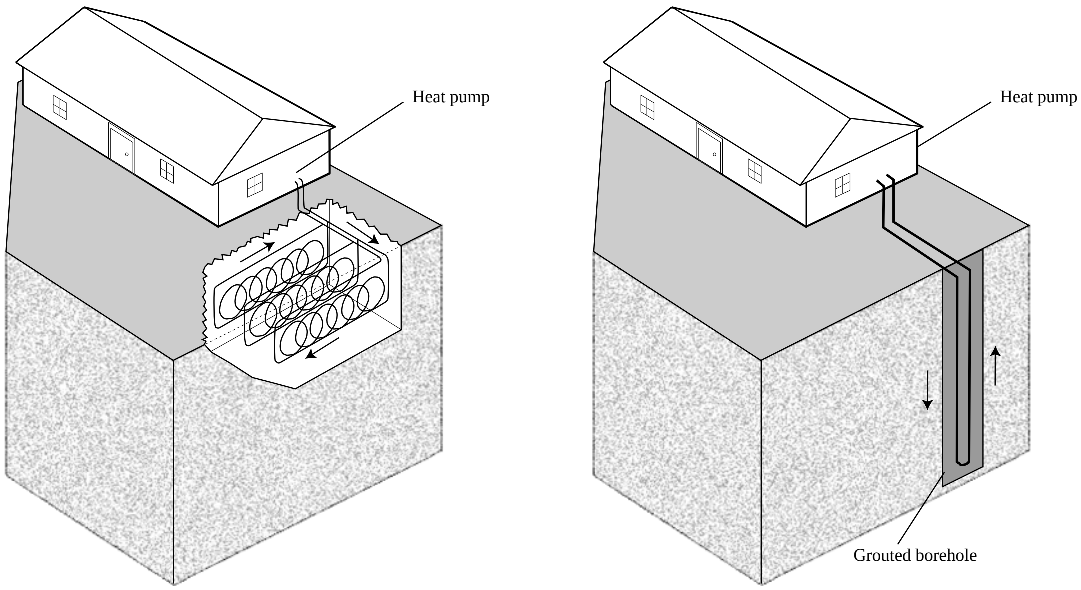
Geothermal heat pumps transfer heat between buildings and the subsurface using the same principles that are used in typical home refrigerators. In home refrigerators, a fluid that boils at very low temperatures (between 35°F and 45°F) is circulated in thermal contact with the interior of the refrigerator. If the interior temperature is above the boiling temperature of the fluid, the fluid will boil. This boiling fluid extracts heat from the interior of the refrigerator as it circulates and is then passed through a heat exchanger that allows the heat in the fluid to be transferred to the room, which acts as a heat sink. The fluid condenses as it loses heat and is circulated back into contact with the refrigerator interior, and the cycle repeats. For a geothermal heat pump system, the basic principles are the same, except that heat is transferred from the room to the earth when operating in cooling mode, and from the earth to the room when operating in heating mode (Figure 2). Although heat pumps rely on the thermodynamic properties of the circulating fluid to accomplish heat transfer, they are dependent on an external electrical supply to power the compressor and to pump fluid in the ground loop.

Figure 2: Schematic Diagram of a Geothermal Heat Pump, Operating in Heating Mode (Modified from Glassley, 2010)



Transferring heat to or from the earth is accomplished by piping a fluid (either water or a water/antifreeze solution) through a plumbing system (i.e., the ground loop) in the subsurface. There are three main types of closed-loop geothermal heat pump plumbing systems, which are horizontal, pond, and vertical (Figure 3). Open-loop systems transfer the piped fluid from a fluid reservoir, such as an aquifer, river or pond, through a heat pump and then release it either to a stream, lake or the subsurface in a once-through configuration. This report considers only closed-loop systems, as they are the most commonly installed geothermal heat pump systems.

Figure 3: Schematic Diagrams of Horizontal Loop (Left) and Vertical Borehole (Right) Systems for Geothermal Heat Pumps



The horizontal loop geothermal heat pump system (Figure 3, left) consists of coiled tubing laid at the bottom of a trench. A trench (or set of trenches) is dug deep enough to be below the frost line to avoid freezing in the winter months but tends to be less than 10 feet deep. Once the trench has been dug out and the tubing laid, it is then filled in with soil and the fluid used for heating and cooling is pumped through the tubing. This method can require a larger amount of land for the tubing to be installed than vertical loop systems.

The pond loop geothermal heat pump system (not shown in Figure 3 but similar to the horizontal loop on the left) arranges the piping on a platform/scaffolding that is sunk into a nearby body of water. This system requires a sufficiently large pond to accomplish adequate heating/cooling.

A vertical loop borehole geothermal heat pump system (Figure 3, right), is composed of vertical tubing inserted into a borehole. The borehole is filled in with an insulating grout to hold the piping in place, to help keep the fluid in the piping from contaminating ground water, and to facilitate heat transfer. This report focuses on the vertical loop geothermal heat pump systems.

1.2 Ground Loop Components for Vertical Boreholes

Vertical ground loop systems consist of boreholes, surficial components, and a heat transferring fluid (Figure 3 - right). The borehole is filled with piping, grout, and a u-tube. Pipe size and type are selected to maximize heat transfer while maintaining mechanical integrity. For this study, the pipe used was Standard Dimension Ratio 9 (SDR9) meaning the outer diameter of the pipe is 9 times the size of the wall thickness. Pipe wall thickness determines how quickly heat can flow from the interior circulating fluid to the surrounding grout and soil/rock. A thicker pipe wall causes more heat to be retained in the piping inhibiting the transmission of heat into the surrounding soil where it can be diffused.

The grout is used for insulation and support to hold the pipes in place. There are many different types of grouts available, each with different material properties. Because this is a study of efficiency, our main concern is the grout's thermal conductivity or its ability to conduct heat. In this project the grout used has a thermal conductivity of 1.2 Btu/(hr*ft*°F), consistent with Bernier (2006).

At the bottom of the borehole is the u-tube. This is a curved tube at the base of the borehole that facilitates return flow to and from the building.

Distributing fluid through the boreholes is accomplished via circulation pump(s) and headers. Circulation pumps are separate from the heat pump and require specific engineering to overcome the resistance, also called "head," of the piping system. In this project, the circulation pump modeled is relatively small (~0.1HP). The pump overcomes resistive forces on the fluid in the tubes, headers, and heat pump due mostly to friction and gravity. The header connects the tops of the pipes in the borehole to the pipes connected to the geothermal heat pump in the building.

The circulating fluid (also known as the working fluid) in the piping depends on the local climate. Colder climates, like Mt. Shasta, require the working fluid to include antifreeze additive to prevent the fluid from freezing in the pipes. Simulations for this project added ethylene glycol to create a 20 percent solution by weight for those climate zones where freezing temperatures occur during a significant part of the winter months. The addition of this amount of ethylene glycol reduces the freezing point of the water to 15°F. Only two cities required antifreeze for this study, Arcata and Mt. Shasta, where the average ground temperatures for the cities are both under 55°F. For all other regions, water was used as the circulating fluid.

1.3 Conditions That Influence Geothermal Heat Pump Performance and Design

Although simple in concept and design, the efficiency and long-term performance of geothermal heat pump installations are affected by a variety of factors. Some of these factors relate to natural site characteristics (such as soil properties and local climate), some to the building properties (size, insulation, orientation, construction methods, etc.) and some to loop design (pump sizes, borehole construction, etc.). Below we discuss some of the key properties that were explicitly considered in this study.

1.4 Soil Thermal Conductivity, Thermal Diffusivity and Saturation

Design of geothermal heat pump subsurface loops requires the ability to predict heat transfer rates. Soils and rocks in which heat transfer rates are slow will experience relatively rapid changes in temperature near boreholes, while fast heat transfer rates will result in relatively small changes in temperature near boreholes. The efficiency of a geothermal heat pump system directly depends on the temperature difference between the heat reservoir surrounding the borehole and the temperature of the circulating fluid in the loop. Designing efficient and sustainable geothermal heat pump installations is critically dependent on the ability to model heat transfer processes in the subsurface.

The most critical parameters that affect heat transfer rates are thermal conductivity, thermal diffusivity, and saturation. This is particularly important in California because of the state's diverse and complex geology (Appendix 1). These properties are specific to a rock/soil type and the local hydrological regime. The thermal conductivity of the underlying rock refers to the ability of the rock to conduct heat. The flow of heat is expressed as:

$$q_{th} = k_{th} * \frac{\nabla T}{\nabla x}$$

$$q_{th} = k_{th} \cdot \nabla T / \nabla x. \qquad (1)$$

where the heat flow is q_{th}, (in units of W/m^2 or Btu/hr-ft^2) and the thermal conductivity as k_{th}(in W/m-K or Btu/hr-ft-^{o}F). ∇T is the temperature gradient over the distance ∇x.

Equation (1) demonstrates that heat flow increases with increasing thermal conductivity, for any given temperature gradient over a given distance. This means that the higher the value of thermal conductivity is of a soil/rock, the easier it is for heat to be absorbed by the soil/rock. Conversely, if the soil/rock has a lower value of thermal conductivity, the soil/rock will act more like an insulator and retard the rate at which heat is transferred to the enclosing soil/rock. Published values of thermal conductivity for various locations and rock types in California are provided in Appendix 2.

Thermal diffusivity, κ, is a measure of the rate at which heat transfer occurs. Thermal diffusivity has the units of m^2/s or ft^2/s. It is defined as the ratio of the thermal conductivity, k_{th} to the heat capacity (by volume) of a material (C_V, in J/m^3-K or Btu/lb-^{o}F):

$$\kappa = k_{th} / C_V. \qquad (2)$$

Heat capacity is the amount of heat required to raise the temperature of a unit volume of a material by 1^o K.

The higher the value of thermal diffusivity for a specific rock, the greater the rate at which heat will spread through the rock. Much like the thermal conductivity, if a material has a low thermal diffusivity value it will act like an insulator.

As with thermal conductivity, thermal diffusivity is specific to a particular soil/rock. It is important, therefore, to obtain measured values for these parameters to develop models for vertical ground loop designs. Because measured values for thermal diffusivity are limited, we developed an approach for estimating thermal diffusivity from thermal conductivity values (which are more commonly available). Loop designs were then modeled over a range of thermal conductivity values, to address the variability of site geology within any particular climate zone. The details of this approach are discussed in more detail in the methodology section.

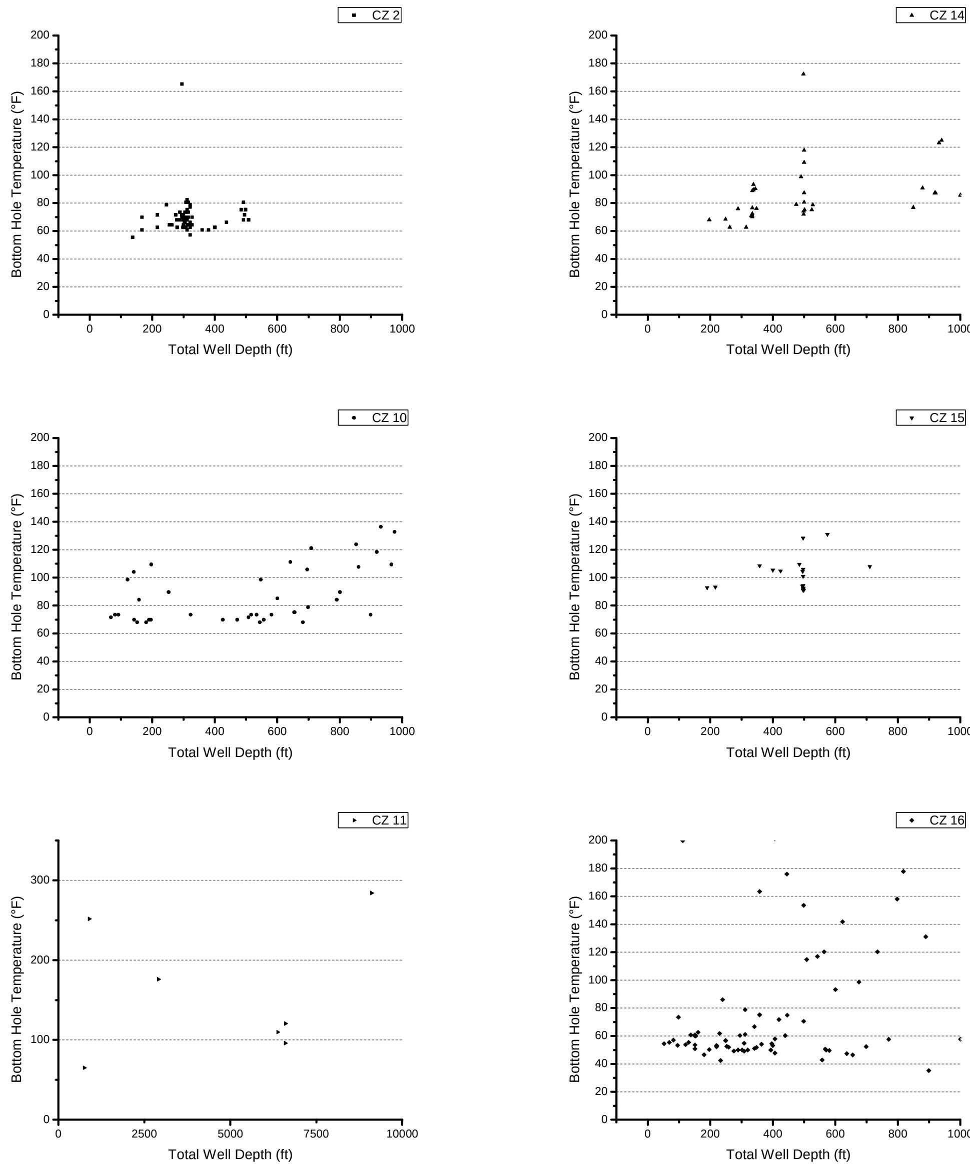
Saturation refers to the percentage of the pore space of a material that contains water. Since the thermal conductivity of air is significantly less than that of water, the more water that is contained in a material the greater the thermal conductivity will be, since the thermal conductivity of water is several times that of air. It is important to take into account the degree of saturation.

1.5 Subsurface Temperature

The efficiency of a geothermal heat pump system is directly related to the temperature difference between the circulating fluid in the loop and the temperature in the subsurface. This is implicit in the expression for thermal conductivity (equation 1).

Although rule-of-thumb approaches have been applied to estimating subsurface temperatures for the design of geothermal heat pump loops, the factors that influence subsurface temperatures are sufficiently different locally and regionally that significant error can be introduced if temperatures are not measured. The subsurface temperature variability at sites in six climate zones in California is substantial, varying from 20^{o}F to more than 100^{o}F (Figure 4). Because of this variability, it is important that site temperatures be established to accurately design an efficient and sustainable geothermal heat pump system.

Figure 4: Temperature as a Function of Depth for California Climate Zones 2, 10, 11, 14, 15 and 16. Data source: Clark et al., 2010

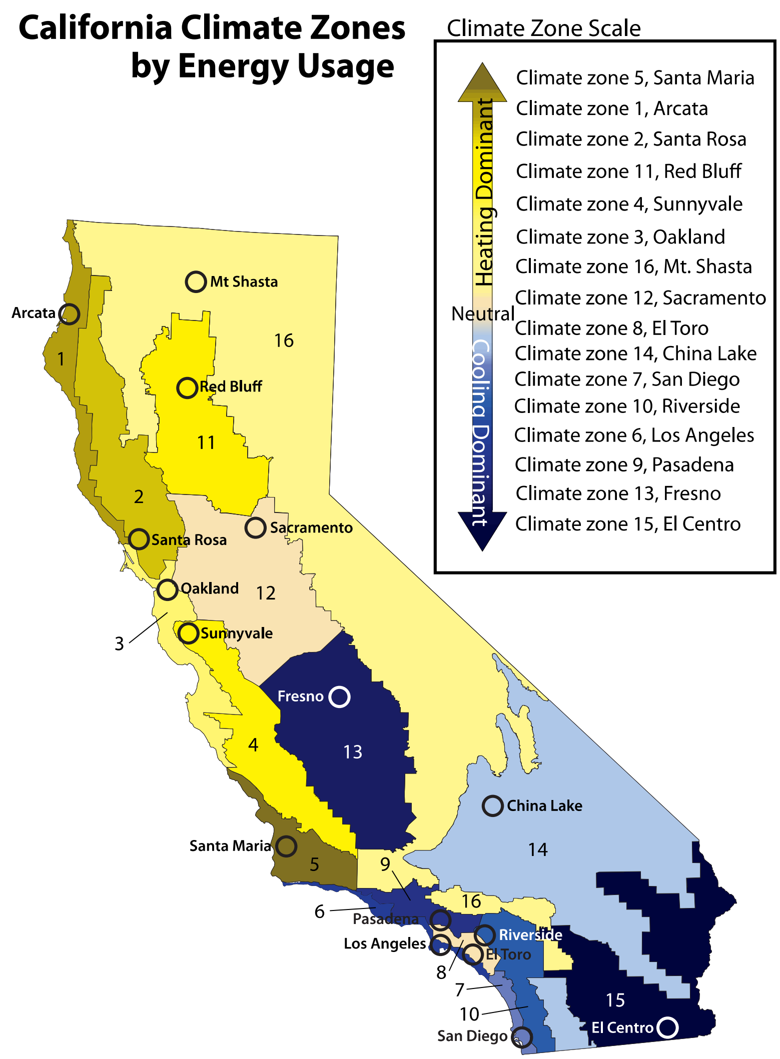


Subsurface temperatures, as a function of depth, were compiled from published data and are presented in Appendix 3.

1.6 Local Climate

One of the primary factors that determine the size of a geothermal heat pump system is the heating and cooling load to which the system must respond. The loads are a direct function of local climate since local climate will influence whether a building will require mainly heating, mainly cooling or approximately equal heating and cooling demands. Building attributes (e.g., orientation, construction quality, insulation, window coverage and type, use patterns, etc.) are also critically important in establishing loads within a given climate zone. In California, 16 climate zones (Figure 5) have been identified (CEC, 1995).

Figure 5: California Climate Zones, as Identified by the California Energy Commission (CEC, 1995)



The representative city for each zone, and the zone identifying number, are shown.

1.7 Temperature Balance

Efficient operation of geothermal heat pump systems relies on a constant subsurface temperature. It is on the basis of this subsurface temperature that the loop design relies. If the subsurface temperature changes significantly from that which was used for the design of the loop, the efficiency of the system will be affected.

Geothermal heat pump systems that operate in both heating and cooling mode must extract approximately as much heat from the subsurface as they deposit, over their design lifetime. In most instances, this time period is expected to be decades. Therefore, in designing a geothermal heat pump system the overall loop characteristics must take into account any energy imbalance due to differences in heating and cooling load. The system design should ensure that the long-term temperature change in the subsurface is minimized. In the modeling this system, loop design was constrained to result in subsurface temperature changes of less than 2°F over twenty years.

1.8 Methodology

To establish the relative benefits of geothermal heat pump deployment in California, a geothermal heat pump system for a model residence was designed for each of the 16 climate zones. Total energy consumption using conventional HVAC equipment was compared to the total energy consumed for a geothermal heat pump system for each climate zone. These results allowed the impact of geothermal heat pump deployment on energy consumption and atmospheric emissions to be evaluated.

Data from the EIA and the Department of Energy (DOE) Building America Program were used to establish a consistent residential design that would allow comparisons from one climate zone to another. These data indicate that an averaged sized residential building had a total conditioned floor area of 1934.2 square feet, in the shape of a rectangle. Northern and southern wall lengths were 38 feet. Eastern and western wall lengths were 50.9 feet. Floor to ceiling height was 12.47 feet. Window area was set to 25 percent of the wall area on each wall; no skylights were included. Attic maximum height was 7 feet and there was assumed a 6-inch window overhang.

To define the attributes of a standard building, the 2007 American Society of Heating, Refrigerating and Air-Conditioning Engineer's (ASHRAE) standards were used (Table 1).

Table 1: ASHRAE 2007 Standard Building Properties

Property	Value used	Units
Roof and ceiling Insulation	35.712	hr*ft^2*F/Btu
Roof solar absorptivity	0.8	
All walls Insulation	14.787	hr*ft^2*F/Btu
All walls solar absorptivity	0.3	
All doors Insulation	0.25	hr*ft^2*F/Btu
Center of Glass Insulation	1.853	hr*ft^2*F/Btu
Solar heat gain coefficient	0.4	

Average ground reflectance	0.2	
Floor R-value	2.109	hr*ft^2*F/Btu
Perimeter insulation R-value	2.109	hr*ft^2*F/Btu
Air infiltration	0.31	1/hr
Air conditioner SEER	8.76	Btu/hr*W
Heating unit efficiency	0.8	
Heating Seasonal Performance Factor	3.413	Btu/hr*W

Latent and sensible internal heat gains were calculated using equations 30 and 31 from the 2005 ASHRAE Handbook-Fundamentals (ASHRAE, 2005). Sensible heat for the internal loads calculated using equation (3) was added to the latent heat from equation (4) to calculate the total internal load of 0.352 W/ft^2. For the floor area of 1934.2 ft^2, with an average occupation assumed to be 2.6 people, or 0.135 people per 100 square feet, the equations become:

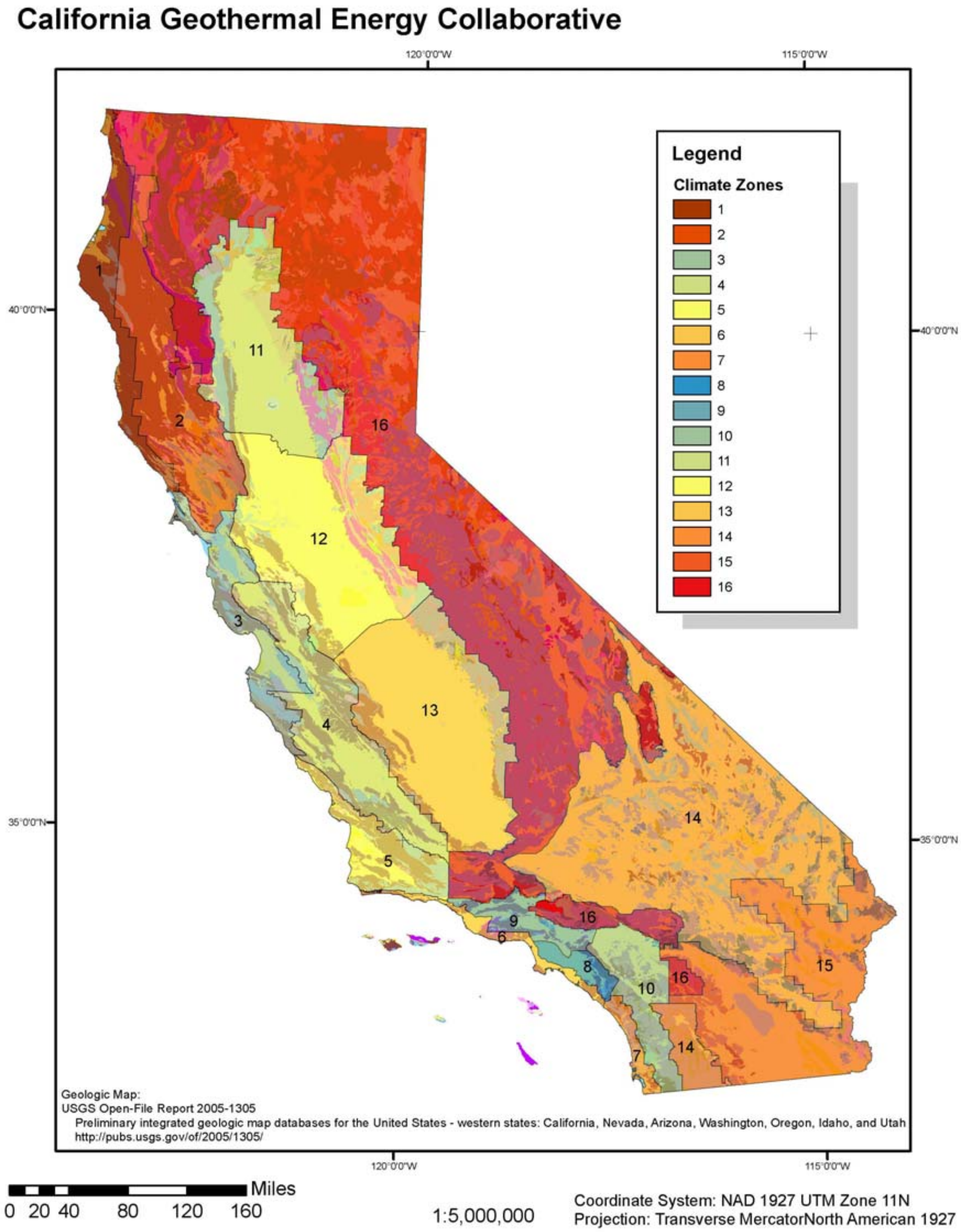
$$464+0.7*(1934.2)+75*(2.6)=2012.94 \text{ Btu/hr} \quad (3)$$

$$68+0.07*(1934.2)+41*(2.6)=309.99 \text{ Btu/hr} \quad (4)$$

Building load calculations were run using the software package ESim (version 2011-03-30). ESim is a building load simulator developed by K. Kissock at the University of Dayton http://academic.udayton.edu/kissock/http/RESEARCH/ESim_files/ESim6Dist.ZIP . Loads were also calculated using Energy Plus software [Energy Efficiency and Renewable Energy (EERE) division of the DOE and the National Renewable Energy Laboratories (NREL)]. Energy Plus load calculations are primarily intended for commercial building use, rather than residential use. As a result, the load calculations from the Energy Plus simulations were consistently lower, in total, than for the ESim calculations. To achieve a conservative result, the ESim calculations were used for this study.

California's 16 climate zones, as defined by the Energy Commission (CEC, 1995), were used to separate the simulation areas. Each climate zone was modeled using data appropriate for the representative city, as defined by the Energy Commission. Climate data for each representative city is provided by the EERE in the Energy Plus Weather format (EPW). This data format is derived from the Typical Meteorological Year 3 (TMY3) data. Data in the EPW TMY3 climate profiles was constructed in 2008 of data from 1973 to 2005. In some cases, there was not a direct EPW file for the representative city and used a close by analog city. Cities that had no direct EPW files were: Sunnyvale, El Toro, El Centro, and Mount Shasta; their respective analogs were Mountain View, Santa Ana, Imperial County Air Port, and Redding.

Figure 6: California Climate Zones Superimposed on the Geological Map of California (See Appendix 1 for a Description of the Geological Units)



Because of the variability of soil thermal conductivity at any given site, resulting from California's complex geology, a range of soil properties were used in the simulations for each representative city (Figure 6). This approach compared the effect of site to site variability, within a given climate zone, as well as the means to compare relative merits of geothermal heat pump installations in different climate zones. The range of thermal conductivity and thermal diffusivity values used in the simulations are given in Table 2.

To determine the respective diffusivity values for the conductivity range used in the simulations, data were compiled from Land et al. (2002) and Cermak (1982) to derive an equation to calculate diffusivity. Thermal diffusivity is a direct function of thermal conductivity, via equation (2), and heat capacity. From a set of 61 measured conductivity and diffusivity values, equation (5) was derived from a linear least squares fit to the data with a goodness of fit (R^2) value of 0.751. Table 2 contains conductivity values with their calculated diffusivity values used in the ground loop simulation.

$$T_d = 0.616113 * T_c - 0.023234 \qquad (5)$$

Soil temperatures were obtained for the representative cities from a standard industry table published by McQuay International (2002). Because of the scatter previously noted in subsurface temperatures, it is important to recognize that use of such a "standard" temperature will inevitably result in introducing some uncertainty in the calculated loop designs. However, by using this standardized approach, consistency between the models is maintained.

Table 2: Computed Thermal Diffusivities, Using Equation (5)

Thermal Conductivity [Btu/(h*ft*°F)]	Thermal Diffusivity (ft^2/s)
0.2	0.0999
0.5	0.2848
1.0	0.5929
1.5	0.9009
2.0	1.2090
2.5	1.5170
3.0	1.8251
3.5	2.1332
4.0	2.4412

The sizing (i.e., loop length) for a vertical borehole model was done using the Premium Ground Loop Design 2010 software package from Gaia, Inc. Energy load values and rates used in the simulations were those obtained from ESim as described above. Also as noted above, it was assumed that a thermally enhanced grout having a conductivity of 1.2 Btu/(h*ft*°F) and one-inch pipe with a standard dimension ratio (SDR) of nine was used in the borehole. Pipe placement was assumed to be close to the outer walls of the borehole with a single return U-tube. Total borehole thermal resistance was 0.208 (h*ft*°F)/Btu; resistance for the pipe only was 0.14. Bore-field configuration was set to one row of two boreholes with one borehole per circuit and 25 feet separation between boreholes (borehole diameter was 6 inches). These parameters were held constant for all ground soil properties in each of the sixteen climate zones. Antifreeze in the form of Ethylene Glycol at 20 percent by weight was added to the fluid for climate zones 1 and 16. Fluid flow in the borehole for the simulation was assumed to be transitional.

1.9 Caveats

As noted previously, geothermal heat pump system design is subject to numerous independent parameters and conditions. The values for these parameters vary from site to site. To precisely establish the impact on energy consumption and atmospheric emissions throughout the state would therefore require a highly detailed data set covering, at high spatial resolution, and measured values for all of the relevant modeling parameters. Such a data set does not exist. Standardized values were used for most of the parameters in the modeling, with the exception of climate, thermal conductivity and thermal diffusivity. The climate data used in the models is appropriate for the reference city in the respective climate zone. As noted, for thermal conductivity and thermal diffusivity the appropriate loop length over a range of values was calculated. This approach allows rigorous comparison of the impacts of geothermal heat pump installations on energy use and greenhouse gas emissions on a statewide basis. However, the results presented in this report are not intended to form the basis for geothermal heat pump designs and installations for any given site. Those can only be accomplished using site-specific data. The complex data set required to model these systems makes it imperative that loop designs for a specific building be accomplished by trained and certified expert designers.

All numerical results are based on calculations derived from commercially available software. Where appropriate, the software source and/or the commercial name of the software package is reported. For most results for specific climate zones, the computed model result is presented as calculated by the software. Although such results are commonly reported at the joule, kW, kWh or fraction of kWh level, there are no estimates of uncertainty provided. It was assumed, therefore, solely on the basis of professional experience, that an uncertainty envelope of at least +/- 10 percent of the reported value is likely. For clarity of presentation, researchers explicitly indicate the uncertainty only in a few specific instances and kept in mind this when considering the numerical results.

1.10 Results

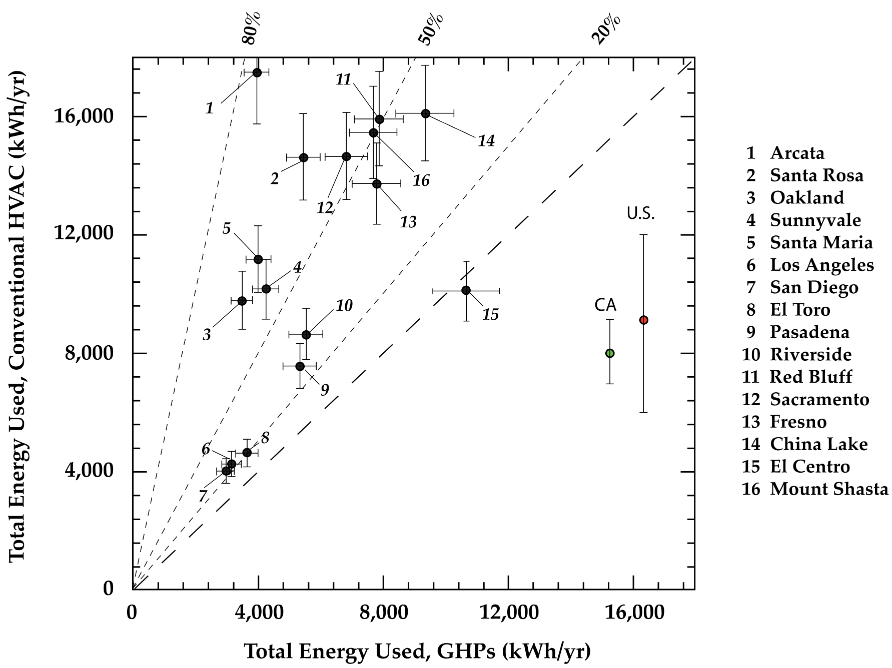
Because of California's diverse climatic conditions, the relative and absolute benefits from geothermal heat pump deployment vary significantly between the various climate zones. The details of the simulations for each climate zone, and the respective results for loop length and other properties, are given individual attention in Appendix 4.

When considered *in total*, all climate zones benefits would be achieved from geothermal heat pumps. These benefits are discussed in detail below. In all cases except when noted, the results presented are referenced to the single residential building basis.

1.11 Energy Use

Because of their efficiency, geothermal heat pump systems can have a dramatic effect on energy consumption especially when compared to the energy consumption of conventional HVAC systems (Figure 7). Points falling above the dashed diagonal line indicate conditions where more energy is consumed by conventional HVAC equipment than for geothermal heat pump systems. The bars for each point represent an uncertainty envelope of plus or minus 10 percent of the value. This uncertainty envelope is shown to emphasize that the results are sensitive to assumptions made in the modeling (as discussed above) and that annual variation in local climate can have significant impacts on energy consumption.

Figure 7: Modeled Total Energy Use per Year per Residence, in kWh/yr, for Conventional HVAC Systems (Vertical Axis), Compared to Energy Use Resulting from Use of Geothermal Heat Pump Systems (Horizontal Axis)



The results are presented for each climate zone (numbers refer to climate zones in Figure 5) and shown with uncertainty bars of +/- 10%. The finely dashed lines with percentage values indicate the arrays of values that represent the indicated savings in energy if GHP systems replace conventional HVAC systems. The points labeled CA and U.S. indicate the average energy use for California and the United States, respectively, for conventional HVAC systems, as deduced from data reported by California's main Investor Owned Utilities (for California) and the U.S. Department of Energy's Energy Information Agency (for U.S.).

The results indicate that for all but climate zone 15, which has the greatest cooling load demand, geothermal heat pump systems would reduce energy consumption by between 22 percent and 77 percent per average residence (Table 2). The average climate zone reduction in power use for the entire state would be 44 percent. The results indicate that the greatest reduction in energy consumption occurs in those climate zones most dominated by heating loads (see Figure 5). This reflects the relatively higher efficiency of geothermal heat pump systems operating in heating mode as opposed to cooling mode. Nevertheless, even for the most strongly cooling-dominated climate zone, total energy use using a geothermal heat pump system overlaps that of a conventional HVAC system, at the 10 percent uncertainty level. However, it must be emphasized that state population obviously varies tremendously between climate zones. The greatest population concentrations are in climate zones 3, 6, 7, 9 and 10. For these zones the average reduction in energy consumption is approximately 35 percent, which is a more realistic measure of the magnitude of energy savings for HVAC purposes that would be realized in California if GHP systems were substituted for conventional HVAC installations.

Table 3: Comparison of Annual Total Energy Consumption of Conventional HVAC Systems and Geothermal Heat Pump Systems, by Climate Zone

Climate Zone	Conventional Energy [kWh]	GHP Energy [kWh]	Difference [kWh]	% Energy Reduction
1	17539.453	3926.300	-13613.153	77.61%
2	14674.521	5431.800	-9242.721	62.98%
3	9828.197	3462.000	-6366.197	64.77%
4	10213.580	4219.600	-5993.980	58.69%
5	11216.380	3979.700	-7236.680	64.52%
6	4288.449	3127.800	-1160.649	27.06%
7	4050.907	2942.900	-1108.007	27.35%
8	4659.066	3620.100	-1038.966	22.30%
9	7598.957	5308.100	-2290.857	30.15%
10	8692.673	5510.200	-3182.473	36.61%
11	15967.354	7845.400	-8121.954	50.87%
12	14706.879	6805.100	-7901.779	53.73%
13	13770.913	7775.400	-5995.513	43.54%
14	16161.329	9318.900	-6842.429	42.34%
15	10147.299	10650.900	503.601	-4.96%
16	15510.346	7666.800	-7843.546	50.57%
			Average =	44.26%

1.12 Emissions

The impact of geothermal heat pump systems on energy use will directly influence emissions of greenhouse gases and other atmospheric contaminants by changing natural gas and electrical demand. Conventional residential heating in California is predominately accomplished by burning natural gas. For cooling, conventional HVAC equipment is primarily powered by utility-scale electrical generation. Electrical supply in California comes from in-state generation facilities and out-of-state suppliers. The fuels used for these generation facilities vary from region to region, source to source and by equipment used for energy conversion. The primary fossil fuel sources for electricity generated for use in California (California Independent System Operators "Power Sources Data" for 2010) are natural gas (84.38 percent), oil (0.036 percent) and coal (15.58 percent). Greenhouse gas emissions for each fuel are expressed as an 'emission factor' which is the amount of greenhouse gas (in kg) emitted per kWh (Table 4).

Table 4: Emission Factors for Fossil Fuels Used in Power Generation in California

The values in parentheses are the percentage of the indicated fuel source in the overall energy mix.

Gas	Natural Gas (84.38%) kg/kWh	Oil (0.036%) kg/kWh	Coal (15.58%) kg/kWh
CO_2	0.188	0.254	0.333
NOx	1.70E-04	2.40E-04	8.93E-16
SO_2	9.648E-07	3.82E-04	1.86E-03

Source: California Independent System Operators "Power Sources Data" for 2010.

For in-home heating using natural gas (methane), a factor of 0.23 kg CO_2/kWh, based on the carbon content of burned methane was used. The calculated emissions are shown in Figures 8-10.

Figure 8: CO_2 Emissions (kg/yr), for Conventional HVAC Systems (Vertical Axis), Compared to CO_2 Emissions Resulting from Use of Geothermal Heat Pump Systems (Horizontal Axis)

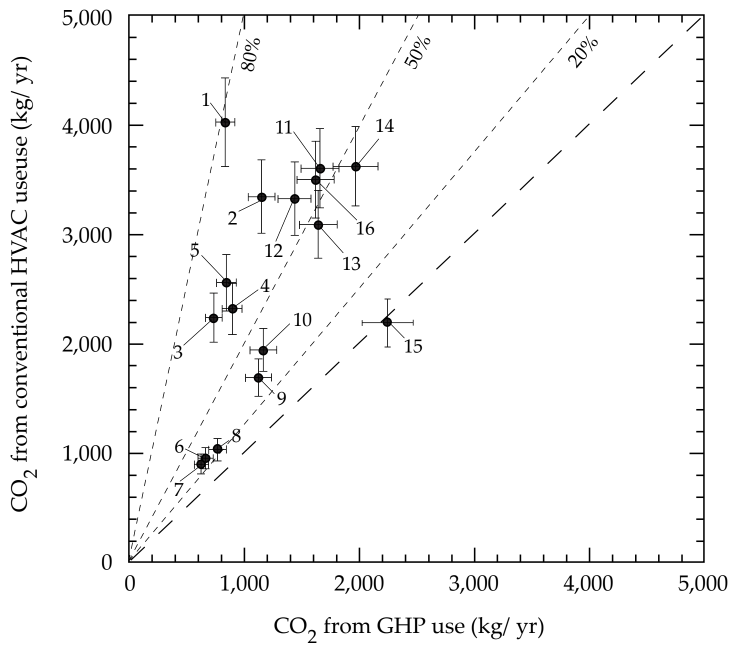


Figure 9: NOx Emissions (kg/yr), for Conventional HVAC Systems (Vertical Axis), Compared to NOx Emissions Resulting from Use of Geothermal Heat Pump Systems (Horizontal Axis)

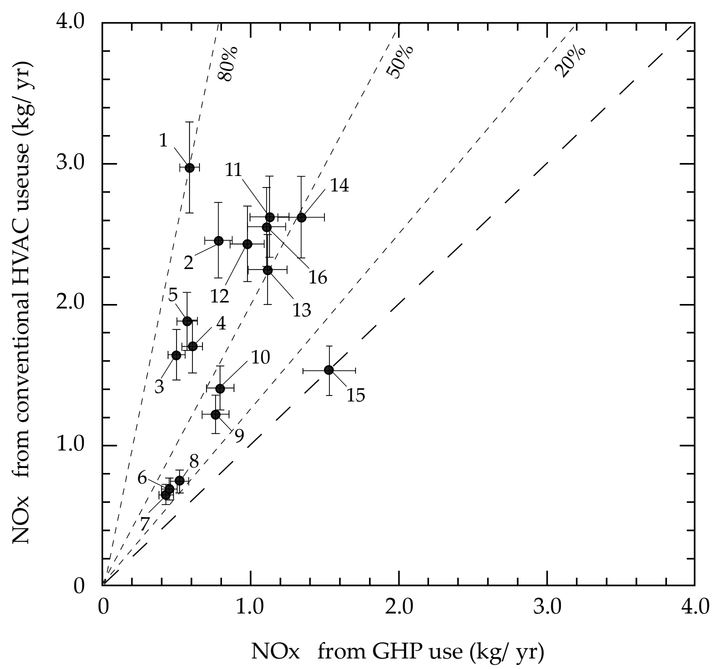
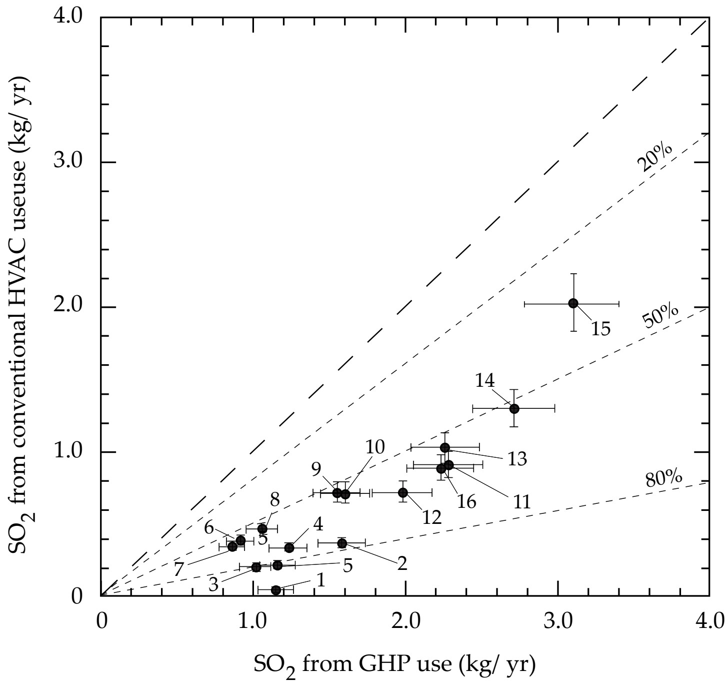


Figure 10: SO_2 Emissions (kg/yr), for Conventional HVAC Systems (Vertical Axis), Compared to SO_2 Emissions Resulting from Use of Geothermal Heat Pump Systems (Horizontal Axis)

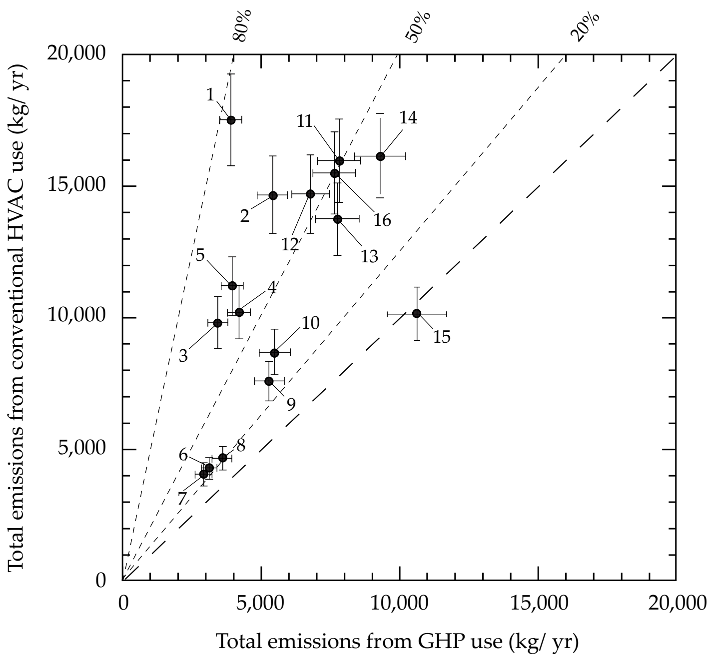


The amount of renewable energy provided to the grid varies significantly by season and time of day. This effect was not considered in these calculations. If sufficient data were to become available, this affect should be taken into account. Although not accounted for currently, the overall consequence would be to reduce the calculated conventional emissions by a few percent.

The results demonstrate that CO_2 and NOx emissions are reduced by about the same amount as energy consumption, on a percentage basis. The emissions of SO_2, however, increase. This contrast reflects the fact that the heating load demand for conventional systems is primarily met using natural gas, which has relatively low SO_2 emissions, while heating demand that is met using geothermal heat pump systems is exclusively powered using electrical generation, which has relatively greater SO_2 emissions.

Deploying geothermal heat pump systems in California would dramatically reduce the air pollutants created by nearly every climate zone (Figure 11).

Figure 11: Total Atmospheric Emissions (kg/yr), for Conventional HVAC Systems (Vertical Axis), Compared to the Total Emissions Resulting from Use of Geothermal Heat Pump Systems (Horizontal Axis)



1.13 Conclusions

Deploying geothermal heat pump systems in California has lagged behind many other states. The reasons are many including a lack of information regarding the potential benefits of such systems. Additionally, the performance of these systems is sensitive to many variables, including local climate patterns and geological properties. This variability has made it difficult to provide general guidance to prospective users. Without clear information regarding the benefits for various regions, and lack of financial incentives that exist for other energy efficient and renewable energy technologies, there has been little incentive to pursue their use. This report provides an initial evaluation of the impacts geothermal heat pump systems may have on energy use and emissions of CO_2, NOx and SO_2.

This analysis show that energy use would be reduced in fifteen of California's sixteen climate zones and virtually unmodified in the remaining climate zone. Energy savings ranged between 22 percent and 77 percent, with an average savings of 44 percent by climate zone. Taking into account variation in population across climate zones, the potential energy savings in the state could be as high as 35 percent of the energy used for HVAC. The climate zones for which the greatest reductions were achieved were those zones dominated by heating demand. Climate zones for which cooling load dominates energy use saw smaller reductions in energy consumption, but were still within the 20 percent to 40 percent range, which is significant.

Reduction of CO_2 and NOx emissions closely followed those of energy use (on a percentage basis). The SO_2 emissions generally increased, reflecting the difference in energy sources in heating and cooling cycles, and the lower efficiency of geothermal heat pump systems in their cooling cycles relative to their heating cycles. Even so, the total emission of atmospheric pollutants was reduced by percentages closely following those observed for reductions in energy use.

These results provide striking evidence that deployment of geothermal heat pump systems on a large scale could significantly contribute to the ability of California to meet its emissions goals, as outlined in Assembly Bill 32 (2006; Global Warming Solutions Act of 2006). In addition, since California uses approximately 35 percent to 40 percent of its energy on building heating and cooling, wide spread deployment of geothermal heat pump systems could significantly contribute to lower energy demand.

The detailed analysis and modeling carried out in this research points to several areas of further work that should be accomplished to resolve key uncertainties. These research activities are:

1. Conduct an analysis of previously installed geothermal heat pump systems in California. These systems have been deployed in homes, schools, and public buildings in a number of places around the state since the 1970s. By recording the long-term performance of these systems, improvements in design approaches and in system efficiencies are likely to be uncovered.

2. Establish an on-going database in which subsurface information is accumulated as it becomes available. Data to be included would be thermal conductivity and diffusivity and subsurface temperature. In addition, information on groundwater flow vectors (direction and velocity) should be included as available. This information could be used in periodic updates of assessments of geothermal heat pump use in the state, and could be made available to modelers and designers, as a means of establishing publicly accessible resources for reducing energy use and emissions.

3. Conduct research on the local costs of installing such systems, with the goal of identifying those technological improvements that could most dramatically reduce upfront costs for installation of these energy efficient systems.

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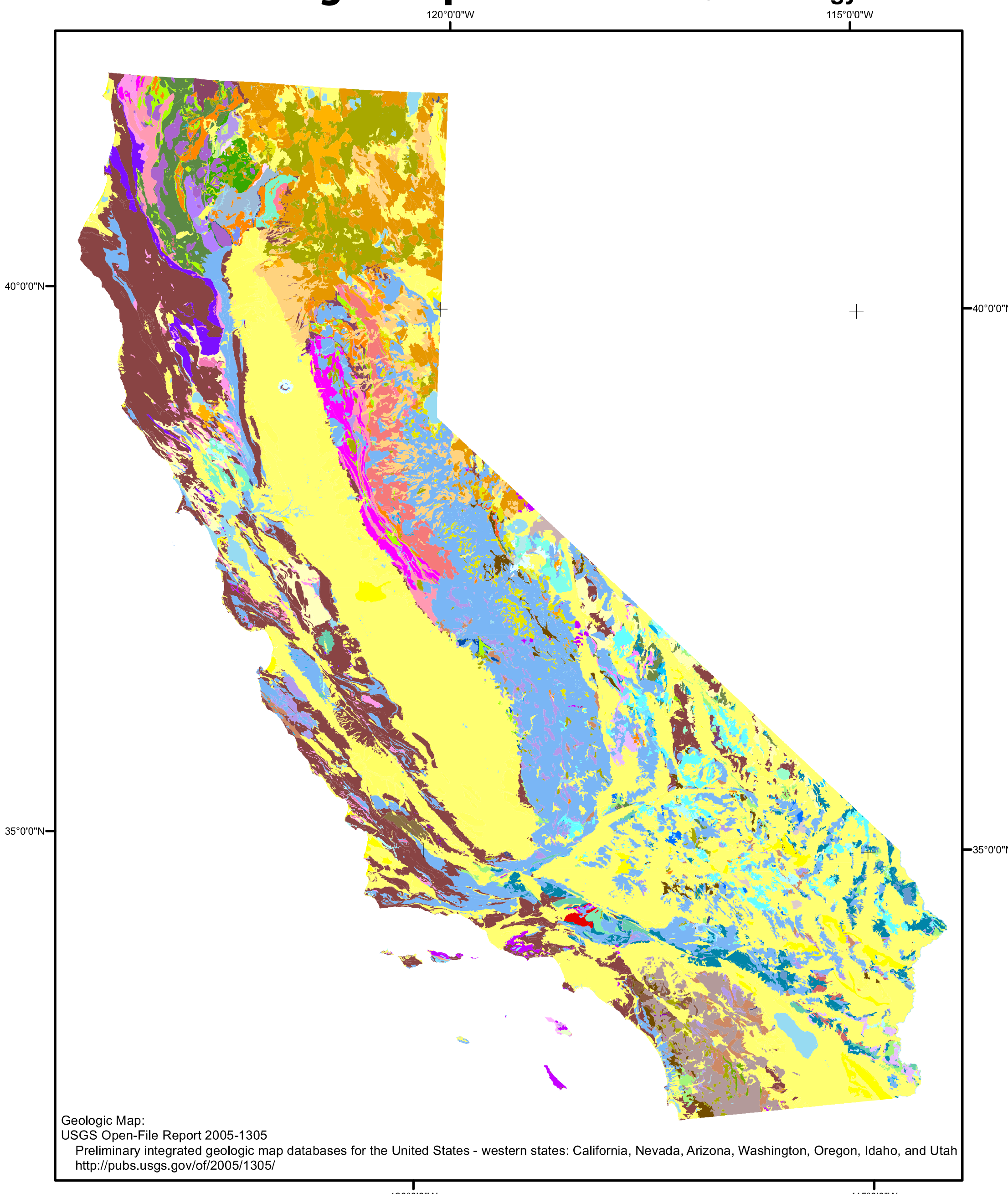
APPENDIX A:
Geology of California

California Geologic Map

California Geothermal Energy Collaborative



Miles
0 20 40 80 120 160

1:5,000,000

Coordinate System: NAD 1927 UTM Zone 11N
Projection: Transverse MercatorNorth American 1927

Map Legend for California Geologic Map

California Geothermal Energy Collaborative

- Alluvium, terrace, Q
- Andesite (QHv3,Qv1, Qv1?, Ti1, Tv10, Tv17, Tvp6, QHv1, Qv3, PZv2, QHvp1, Qvp1, Qvp1?, Tvp9)
- Anorthosite, gabbro, grpCA2
- Argillite (C8, PZ2, PZ9, J4, PZ6, PZ4)
- Basalt (Qv8, Tv19, Tv9, Qv6, Ti5, Tv11, Tv13,Tv5, Tv6, Tv8, Tv4, Tvp2, Qv5, Ti6, Tv12, Tv15, mv1, Qv7, Qv7?, Qvp4)
- Blueschist, metasedimentary rock, KJfs
- Chert, graywacke, C6
- Conglomerate (EOc2, Kl?, Ku?, Tc,OGc2?)
- Dacite (Ti8, Ti2, Tv1, Tv3, Tv3)
- Diorite, (grMZ6, grMZ?, grpCA4, grpCA?, grMZ5)
- Dolostone (dolomite), (SO1, SO4, SO2, SO3)
- Dune sand, lake or marine deposit (non-glacial), (Qs1, Qs2)
- Felsic volcanic rock (K3, MZv3, MZv4)
- Gabbro (Ti9,gb1, gb2)
- Glacial drift, Qg
- Gneiss (PZ7,pCA2, pCAc,sch9)
- Granite (grpCA3,grpCA1)
- Granodiorite (grPZ1, grMZ1, grMZ3, grMZ4)
- Greenschist (sch8, PZv6, MZv1)
- Hornfels (C7, PZ3, TR7, J6)
- Intermediate volcanic rock, felsic volcanic rock, (MZv5, PZv5, PZv1, PZv3, mv2)
- Landslide, Qls
- Limestone (P4, D1, ls, C2, P1, PZ1, TR4)
- Mafic/Intermediate volcanic rock, MZv2
- Marble, limestone, C1
- Melange, KJfm
- Metasedimentary rock, metavolcanic rock, PZ5
- Metavolcanic rock (PZv4, sch3)
- Mica schist (sch4, sch2)
- Mudstone (TR1, TR2, PZ8, C4, EO, J2, K1, Kl, PN2)
- Orthoquartzite, felsic volcanic rock, J3
- Pelitic schist, mica schist, sch1
- Peraluminous granite, grCZ?
- Peridotite (um1, um2)
- Phyllite, marble, P2
- Plutonic rock (gr1, gr2, gr3, gr-m)
- Quartz diorite, grCZ2
- Quartz monzonite (grCZ1, grPZ2)
- Quartzite, chert, C5
- Rhyolite (QHv2, QHv5, Ti3, Qv2, Qv4, Qvp3, Qvp2, Ti7, Tv16, Ti4, Tv14, Tvp1, Tvp3, Tvp4, Tvp7, Tvp8, QHvp2, Tv2, Qvp5, Tvp5)
- Sand, gravel, OGc1?
- Sandstone (K?1, K?2, Ku-PE, Ml?, Mlc, OGc1, OGc2, QPOc, CA, TR6, EO-PN, EOc1, K2, KJf1, Ku1, Ku2, Ml, OG, PN1, PO, TK, pCA1, PN3)
- Schist (sch10, sch7, m, sch5, sch11, KJf2, sch6)
- Serpentinite, peridotite, um3
- Shale (D2, C3)
- Siltstone (J?, Ml+KJfs)
- Slate (J1, P3, TR5, J5, TR3)
- Tephrite (basanite) (QHv4, Tv18)
- Tonalite, quartz diorite, grMZ2
- Trachybasalt, Tv7
- Water

APPENDIX B:
Thermal Conductivities of Soils in California

Thermal conductivity values are tabulated in spreadsheet format and can be accessed at:

http://cgec.geology.ucdavis.edu/ghpstudy.php

At that website, click on the "Data Portal" expansion box and select "Thermal Conductivity Data Set". You will then be able to download an Excel spreadsheet that has tabs for California thermal conductivity data.

APPENDIX C:
Subsurface Temperature Data

Subsurface temperature data are tabulated in spreadsheet format and can be accessed at:

http://cgec.geology.ucdavis.edu/ghpstudy.php

At that website, click on the "Data Portal" expansion box and select either "USGS Groundwater Well Data" or "Argonne Geochemical Database". You will then be able to download Excel spreadsheets that have subsurface temperatures, or spring and surface water temperatures.

APPENDIX D: Individual Climate Zone Results

Presented below are the detailed descriptions of the individual climate zones in California. The climate properties that distinguish each zone are provided, as well as the heating and cooling load parameters. Also provided are descriptions of specific modeling parameters used in the ESim load calculations and the GLD software, which are described in the text. Also shown graphically are the results of the GLD calculations in which total borehole length is computed as a function of soil properties (thermal conductivity) for the reference residential building described in the text. Finally, the energy use and emissions for each zone are tabulated.

It is important to note that geothermal heat pump systems require pumps for fluid circulation. Each pump used in a loop system is sized to support the fluid volume and mass it must circulate. Since pump size affects energy consumption, the simulations that were done took into account a specific pump's specifications. We initially conducted simulations using a wide range of possible pumps. However, it became clear that nearly all pumps sized according to the loop parameters consumed approximately the same energy. In order to streamline the simulation process, we therefore randomly selected two pumps with which all of the simulations were done. The list immediately below provides the names of manufacturers that produce pumps useful in geothermal heat pump applications. We do not suggest or imply endorsement of any particular manufacturer.

Name of Heat Pump Manufacturer:	Number of models in GLD: (not counting different sizes of like models)
Addison	3
Calorex Heat Pumps, Ltd	1
Ciat	1
Clean Energy Developments	15
Climate Master	23
Cosfi	1
Dimplex UK Limited	6
Econar	18
Florida Heat Pump	17
GEOFURNACE	2
GeoSmart Energy	7
Hydron	3
Maritime Geothermal Ltd.	3
McQuay	14

Northern Heat Pump	4
Trane	5
Water Furnace	39

Acronyms used:

AEFLH – annual equivalent full load hours

CDD – cooling degree day

COP – coefficient of performance

EER – energy efficiency ratio

GHP – geothermal heat pump

HDD – heating degree day

HVAC – heating, ventilation, air conditioning

CALIFORNIA CLIMATE ZONE 1

Representative City: Arcata, CA

Description of Climate Zone

The climate zone is located west of the Northern California Coast Range. The climate along the Northern coast is characterized by wet, cold winters with cool, foggy summers. Frequent winds in the area make it a climate that requires significant heating to maintain comfort. Though the winters are cold and wet, there is rarely any freezing.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 1.

	Value	Base (°F)
Heating Degree Days	4294.75	65
Cooling Degree Days	19.33	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design is given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Arcata.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	**UNIT**	
Heating Loads		
8am-12	kBTU/hr	26.738

12-4pm	kBTU/hr	13.369
4pm-8pm	kBTU/hr	6.6845
8pm-8am	kBTU/hr	13.369
Annual Equivalent Full-Load Hours	Hours	1185.44
Cooling Loads		
8am-12	kBTU/hr	4.8075
12-4pm	kBTU/hr	9.615
4pm-8pm	kBTU/hr	19.23
8pm-8am	kBTU/hr	9.615
Annual Equivalent Full-Load Hours	Hours	551.86

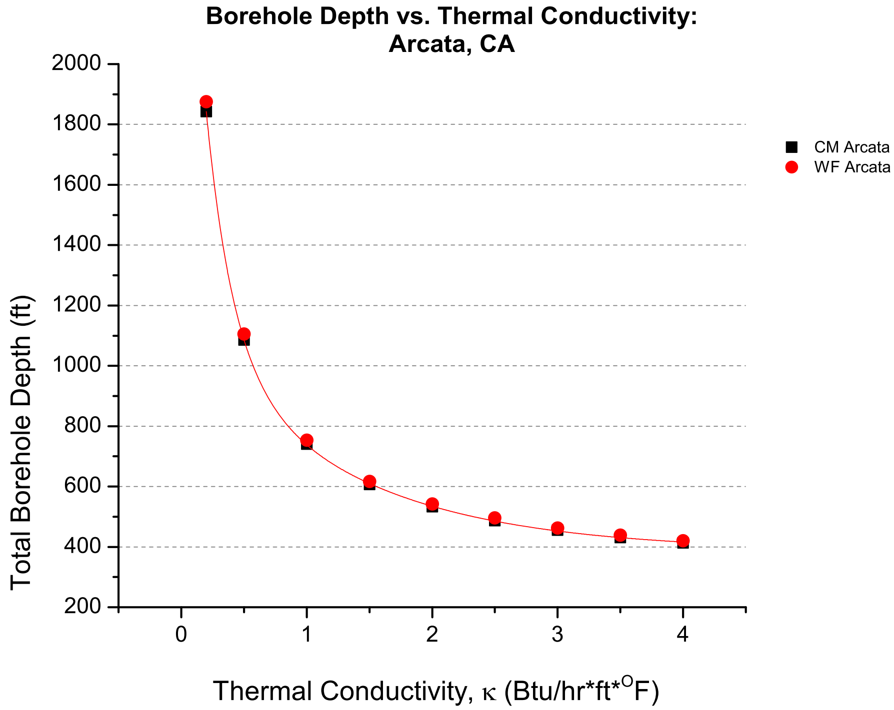
The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Example pump design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	32.1/27.8
Power (cool/heat)	kW	2.95/2.44
EER/COP (cool/heat)		10.9/3.3
Flow (cool/heat)	gpm	4.8/6.7
Partial Load Factor (cool/heat)		0.60/0.96

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values within this climate zone is between 0.8 and 2.0.

Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.



Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)
Climate Master	1018.1	2908.2	3926.3	825.559	1.140	0.564

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	101	17438.453	17539.453
CO_2	Kg	21.237	3270.756	3291.993
SO_2	Kg	0.029	0.017	0.046
NOx	Kg	0.015	2.969	2.984
SUMS	Kg	21.280	3273.742	3295.023

CALIFORNIA CLIMATE ZONE 2

Representative City: Santa Rosa, CA

Description of Climate Zone

This climate zone includes the Northern California Coast Range and the edge of the Northern Central Valley. The climate pattern reflects the interactions of multiple microclimates that result from the varied geography and proximity to the ocean. The winters are cooler but mild and are slightly warmer when compared to Climate Zone 1. The summers are often mild and generally windy.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 2.

	Value	Base (°F)
Heating Degree Days	3118.50	65
Cooling Degree Days	500.25	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	**UNIT**	
Heating Loads		
8am-12	kBTU/hr	26.54

12-4pm	kBTU/hr	13.27
4pm-8pm	kBTU/hr	6.635
8pm-8am	kBTU/hr	13.27
Annual Equivalent Full-Load Hours	Hours	1382.82
Cooling Loads		
8am-12	kBTU/hr	7.971
12-4pm	kBTU/hr	15.942
4pm-8pm	kBTU/hr	31.884
8pm-8am	kBTU/hr	15.942
Annual Equivalent Full-Load Hours	Hours	727.64

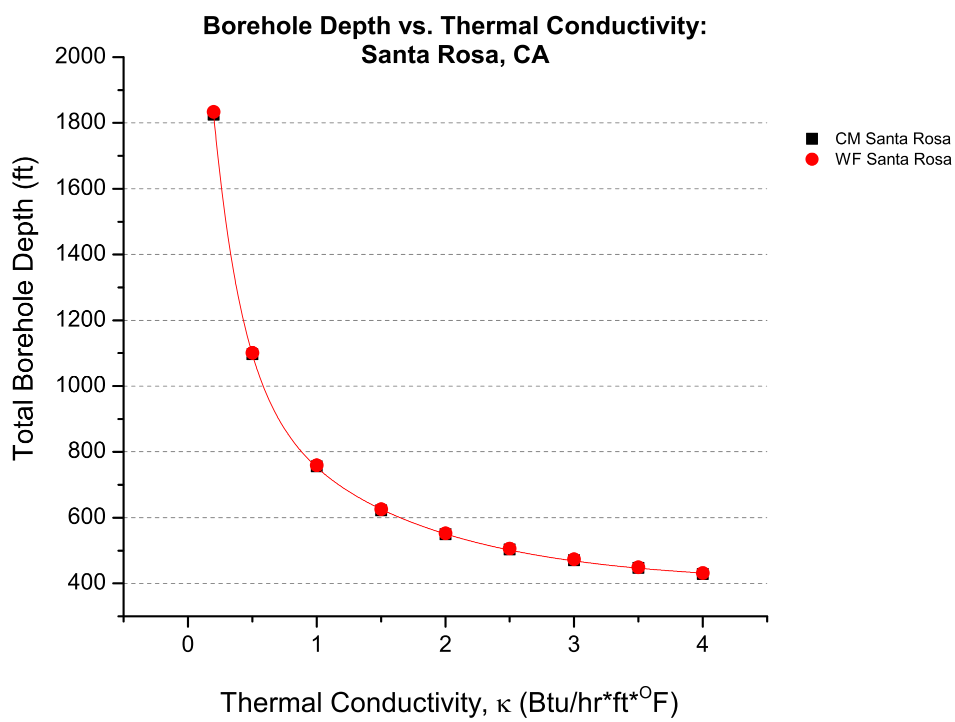
The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	**UNIT**	**Climate Master**
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	32.8/27.8
Power (cool/heat)	kW	2.82/2.43
EER/COP (cool/heat)		11.6/3.3
Flow (cool/heat)	gpm	8.0/6.6
Partial Load Factor (cool/heat)		0.97/0.95

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values within this climate zone is between 1.0 and 2.0.

Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.



Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)
Climate Master	2062.3	3369.5	5431.8	1142.111	1.577	0.781

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	1222	13452.521	14674.521
CO2	Kg	256.942	2523.155	2780.097
SO2	Kg	0.355	0.013	0.368
NOx	Kg	0.176	2.291	2.466
SUMS	Kg	257.473	2525.458	2782.931

CALIFORNIA CLIMATE ZONE 3

Representative City: Oakland, CA

Description of Climate Zone

This climate zone varies greatly with elevation and influences from the coast. The areas with more coastal influence experience moderate temperatures year round, with rain and fog from late summer through winter. Further inland, a diminished fog layer results in elevated summer heat and reduced rainfall. Winter months are mild to moderate with rainfall occurring between October and March.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 3.

	Value	Base (°F)
Heating Degree Days	3071	65
Cooling Degree Days	183.25	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Oakland.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	**UNIT**	
Heating Loads		
8am-12	kBTU/hr	21.303

12-4pm	kBTU/hr	10.6515
4pm-8pm	kBTU/hr	5.32575
8pm-8am	kBTU/hr	10.6515
Annual Equivalent Full-Load Hours	Hours	1173.54
Cooling Loads		
8am-12	kBTU/hr	6.7295
12-4pm	kBTU/hr	13.459
4pm-8pm	kBTU/hr	26.918
8pm-8am	kBTU/hr	13.459
Annual Equivalent Full-Load Hours	Hours	516.38

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	28.0/22.5
Power (cool/heat)	kW	2.36/1.93
EER/COP (cool/heat)		11.9/3.4
Flow (cool/heat)	gpm	6.7/5.3
Partial Load Factor (cool/heat)		0.96/0.94

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values within this climate zone is between 0.8 and 2.0.

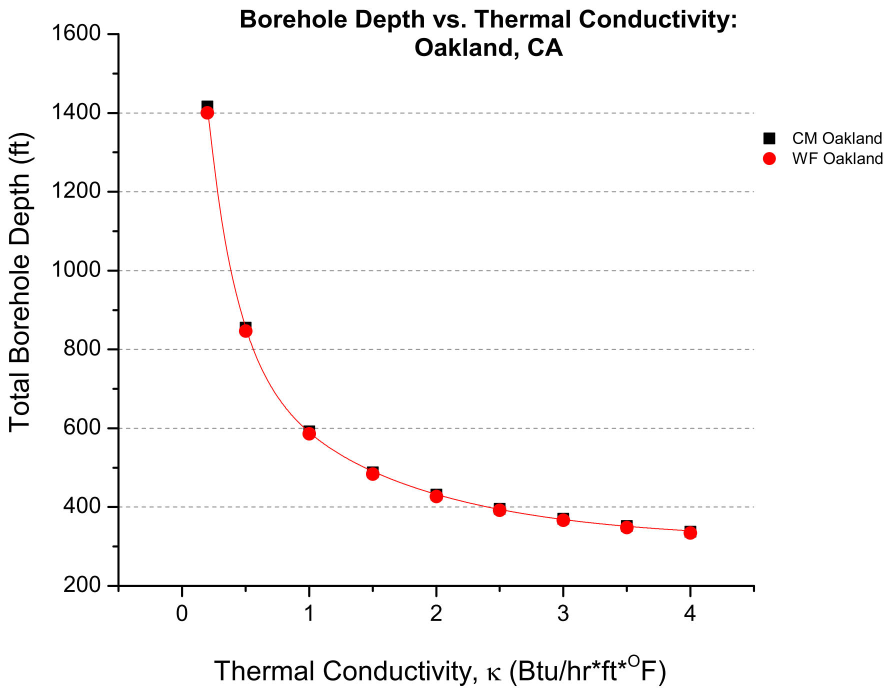


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)
Climate Master	1209.2	2252.8	3462	727.934	1.005	0.498

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	684	9144.197	9828.197
CO2	Kg	143.820	1715.086	1858.906
SO2	Kg	0.199	0.009	0.207
NOx	Kg	0.098	1.557	1.655
SUMS	Kg	144.117	1716.651	1860.769

CALIFORNIA CLIMATE ZONE 4

Representative City: Sunnyvale, CA

Description of Climate Zone

The Central Coast Range experiences some ocean influences that help keep temperatures in this climate zone from reaching extreme values. The seasons are well defined with colder winters requiring heating on many of the days. The summers are warm enough that cooling becomes necessary. Many days through the year are clearer due to the coastal range blocking the majority of the fog and high winds from the Bay Area.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 4.

	Value	Base (°F)
Heating Degree Days	2547.5	65
Cooling Degree Days	665.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Sunnyvale.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	
Heating Loads		
8am-12	kBTU/hr	20.536
12-4pm	kBTU/hr	10.268
4pm-8pm	kBTU/hr	5.134
8pm-8am	kBTU/hr	10.268
Annual Equivalent Full-Load Hours	Hours	1207.64
Cooling Loads		
8am-12	kBTU/hr	6.33375
12-4pm	kBTU/hr	12.6675
4pm-8pm	kBTU/hr	25.335
8pm-8am	kBTU/hr	12.6675
Annual Equivalent Full-Load Hours	Hours	884.15

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	24.8/22.5
Power (cool/heat)	kW	2.38/1.92
EER/COP (cool/heat)		11.7/3.4
Flow (cool/heat)	gpm	6.3/5.1
Partial Load Factor (cool/heat)		0.91/0.91

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

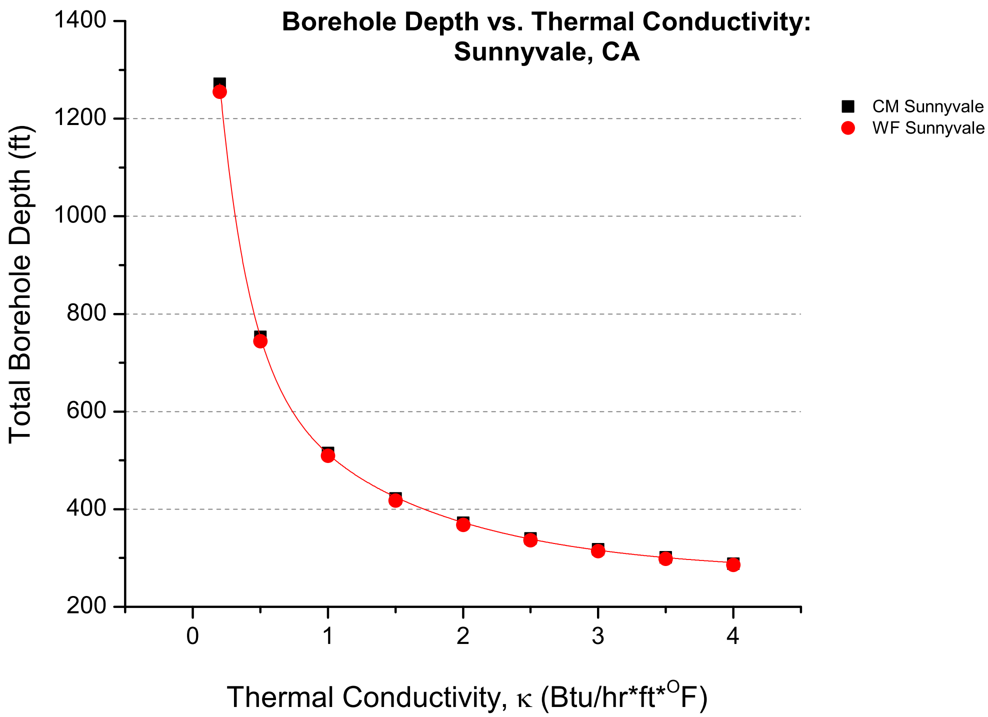


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	1984.8	2234.8	4219.6	887.229	1.225	0.607

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	**Cooling**	**Heating**	**Total**
Yearly Energy	kWh/yr	1128	9085.580	10213.580
CO2	Kg	237.178	1704.091	1941.269
SO2	Kg	0.328	0.009	0.336
NOx	Kg	0.162	1.547	1.709
SUMS	Kg	237.667	1705.647	1943.315

California Climate Zone 5

Representative City: Santa Maria, CA

Description of Climate Zone

Climate Zone 5 is located along the southern Central coast. The summer months are warm and slightly windy with temperatures cooling down in the evenings. Fog is common during the morning and evening hours. The winters are cold but not sever enough to cause frost.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 5.

	Value	Base (°F)
Heating Degree Days	2654	65
Cooling Degree Days	463.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	

Heating Loads		
8am-12	kBTU/hr	24.126
12-4pm	kBTU/hr	12.063
4pm-8pm	kBTU/hr	6.0315
8pm-8am	kBTU/hr	12.063
Annual Equivalent Full-Load Hours	Hours	1185.44
Cooling Loads		
8am-12	kBTU/hr	6.65925
12-4pm	kBTU/hr	13.3185
4pm-8pm	kBTU/hr	26.637
8pm-8am	kBTU/hr	13.3185
Annual Equivalent Full-Load Hours	Hours	551.86

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	32.5/27.6
Power (cool/heat)	kW	2.87/2.42
EER/COP (cool/heat)		11.3/3.3
Flow (cool/heat)	gpm	6.7/6.0
Partial Load Factor (cool/heat)		0.82/0.87

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

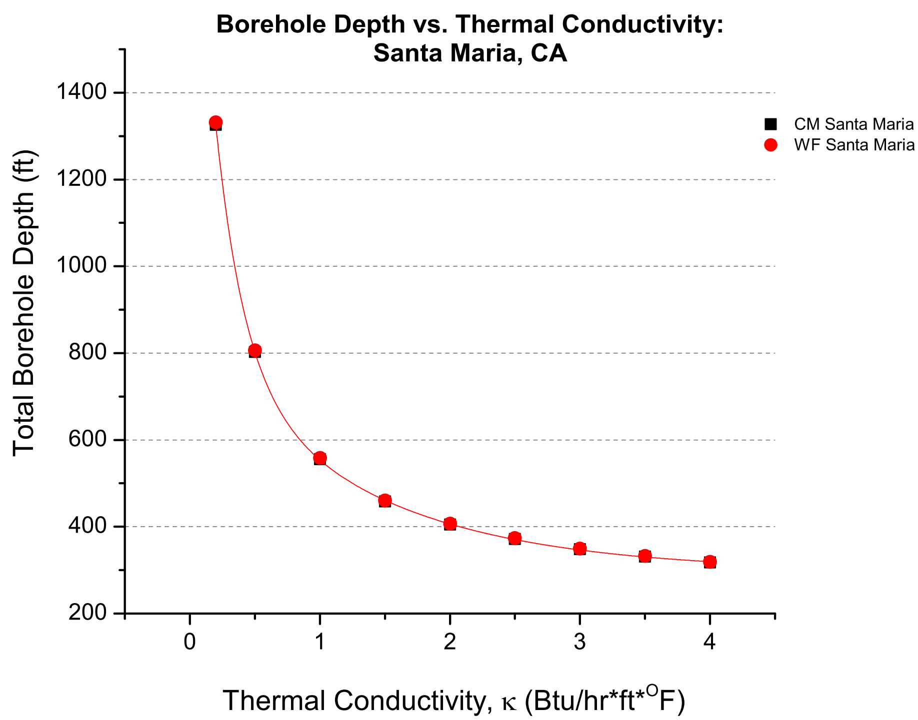


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling)	Yearly Electricity (Heating)	Yearly Electricity (Total)	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

	[kWh/yr]	[kWh/yr]	[kWh/yr]			
Climate Master	1345.1	2634.6	3979.7	836.787	1.156	0.572

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	724	10492.380	11216.380
CO2	Kg	152.231	1967.951	2120.182
SO2	Kg	0.210	0.010	0.220
NOx	Kg	0.104	1.787	1.891
SUMS	Kg	152.545	1969.748	2122.293

California Climate Zone 6

Representative City: Los Angeles, CA

Description of Climate Zone

This climate zone includes several miles of inland area with low or nonexistent hills. The Pacific Ocean is relatively warm and maintains a mild climate. Most of the rainfall occurs during the warm, mild winter months. The summers are cooler due to winds coming from offshore. The winds can bring humidity from the ocean, or hot, dry air from the desert. The humidity level drops quickly the further inland one goes.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 6.

	Value	Base (°F)
Heating Degree Days	1383	65
Cooling Degree Days	741.5	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	
Heating Loads		
8am-12	kBTU/hr	14.817
12-4pm	kBTU/hr	7.4085
4pm-8pm	kBTU/hr	3.70425
8pm-8am	kBTU/hr	7.4085
Annual Equivalent Full-Load Hours	Hours	553.42
Cooling Loads		
8am-12	kBTU/hr	6.0975
12-4pm	kBTU/hr	12.195
4pm-8pm	kBTU/hr	24.39
8pm-8am	kBTU/hr	12.195
Annual Equivalent Full-Load Hours	Hours	1086.51

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	27.7/21.9
Power (cool/heat)	kW	2.39/1.90
EER/COP (cool/heat)		11.6/3.4
Flow (cool/heat)	gpm	6.1/3.7
Partial Load Factor (cool/heat)		0.88/0.68

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

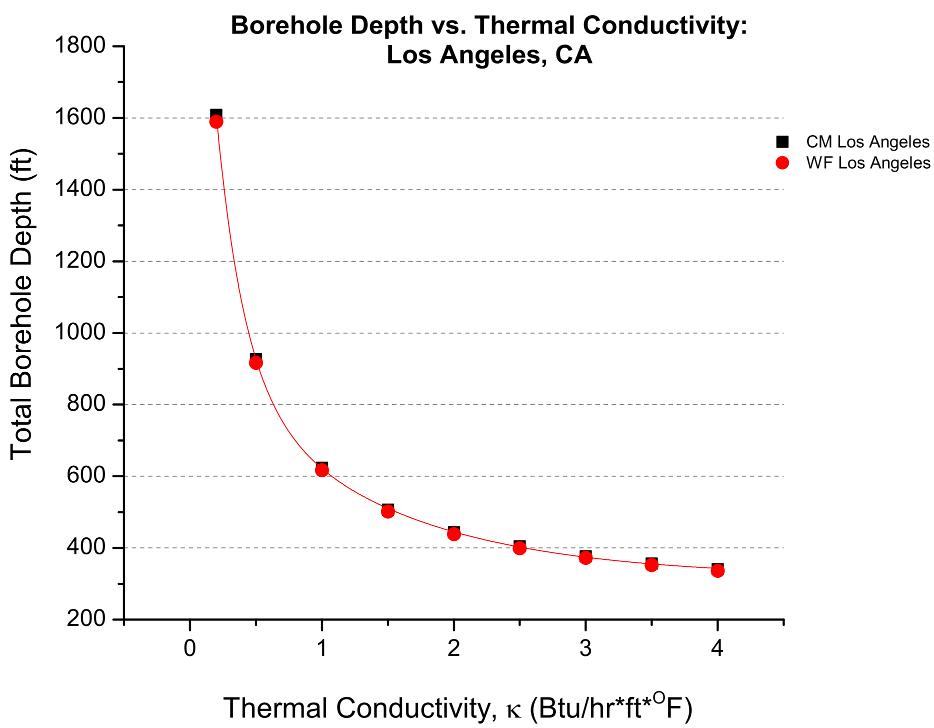


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	2376.5	751.3	3127.8	657.663	0.908	0.450

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	1299	2989.449	4288.449
CO2	Kg	273.133	560.701	833.834
SO2	Kg	0.377	0.003	0.380
NOx	Kg	0.187	0.509	0.696
SUMS	Kg	273.697	561.213	834.910

California Climate Zone 7

Representative City: San Diego, CA

Description of Climate Zone

This climate zone is the southernmost coastal region of California. The climate is very mild due to the warmer ocean water. Although the ocean controls the temperature most of the time, a change in wind direction may bring in hot, dry desert winds. Even with the moderate climate, the summer temperatures get high enough to require cooling and winteres can be cool enough to require heating.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD degree days for Climate Zone 7.

	Value	Base (°F)
Heating Degree Days	1496.50	65
Cooling Degree Days	865.25	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in San Diego.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	**UNIT**	
Heating Loads		
8am-12	kBTU/hr	15.772

12-4pm	kBTU/hr	7.886
4pm-8pm	kBTU/hr	3.943
8pm-8am	kBTU/hr	7.886
Annual Equivalent Full-Load Hours	Hours	494.55
Cooling Loads		
8am-12	kBTU/hr	6.18
12-4pm	kBTU/hr	12.36
4pm-8pm	kBTU/hr	24.72
8pm-8am	kBTU/hr	12.36
Annual Equivalent Full-Load Hours	Hours	1007.28

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	27.7/22.0
Power (cool/heat)	kW	2.39/1.90
EER/COP (cool/heat)		11.6/3.4
Flow (cool/heat)	gpm	6.2/3.9
Partial Load Factor (cool/heat)		0.89/0.72

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

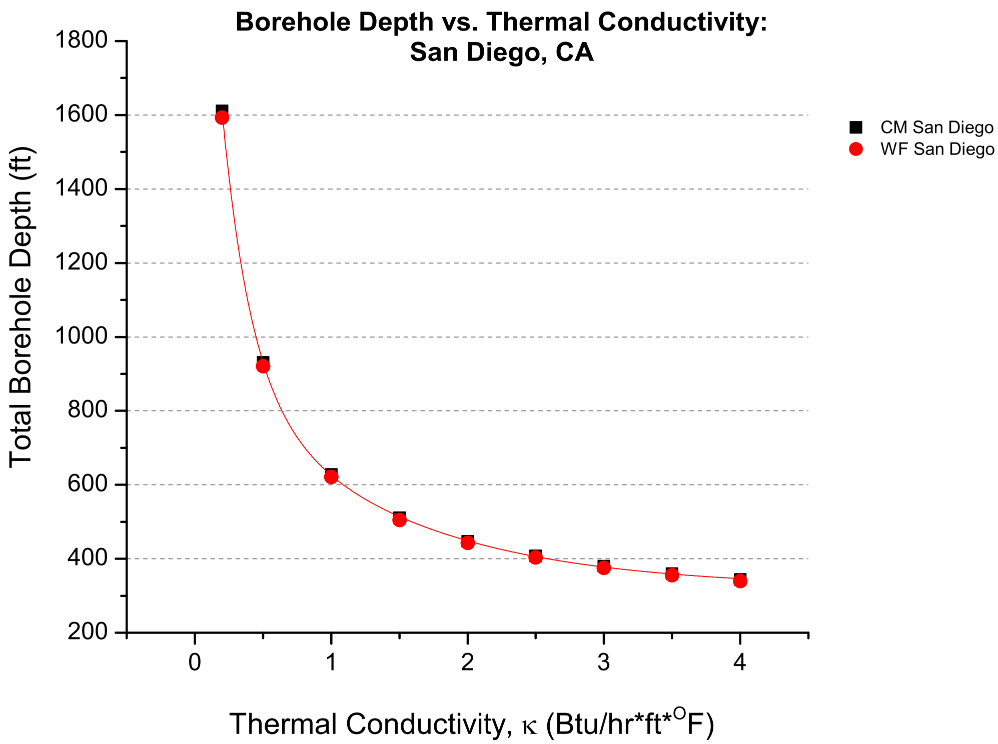


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)
Climate Master	2227.7	715.2	2942.9	618.786	0.854	0.423

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	1208	2842.907	4050.907
CO2	Kg	253.999	533.216	787.214
SO2	Kg	0.351	0.003	0.353
NOx	Kg	0.174	0.484	0.658
SUMS	Kg	254.523	533.703	788.226

California Climate Zone 8

Representative City: El Toro, CA

Description of Climate Zone

Because this zone is more inland and marginally affected by the coast, the summers are warmer, and the winters are cooler. Cooling and heating are necessary for both summer and winter respectively. The majority of rainfall occurs during the winter and frosts are not a threat. Because the zone is further from the coast, there is little to no fog.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD degree days for Climate Zone 8.

	Value	Base (°F)
Heating Degree Days	1480.75	65
Cooling Degree Days	1072	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in El Toro.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	

Heating Loads		
8am-12	kBTU/hr	17.643
12-4pm	kBTU/hr	8.8215
4pm-8pm	kBTU/hr	4.41075
8pm-8am	kBTU/hr	8.8215
Annual Equivalent Full-Load Hours	Hours	470.44
Cooling Loads		
8am-12	kBTU/hr	6.392
12-4pm	kBTU/hr	12.784
4pm-8pm	kBTU/hr	25.568
8pm-8am	kBTU/hr	12.784
Annual Equivalent Full-Load Hours	Hours	1263.30

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	27.8/22.2
Power (cool/heat)	kW	2.38/1.91
EER/COP (cool/heat)		11.7/3.4
Flow (cool/heat)	gpm	6.4/4.4
Partial Load Factor (cool/heat)		0.92/0.80

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

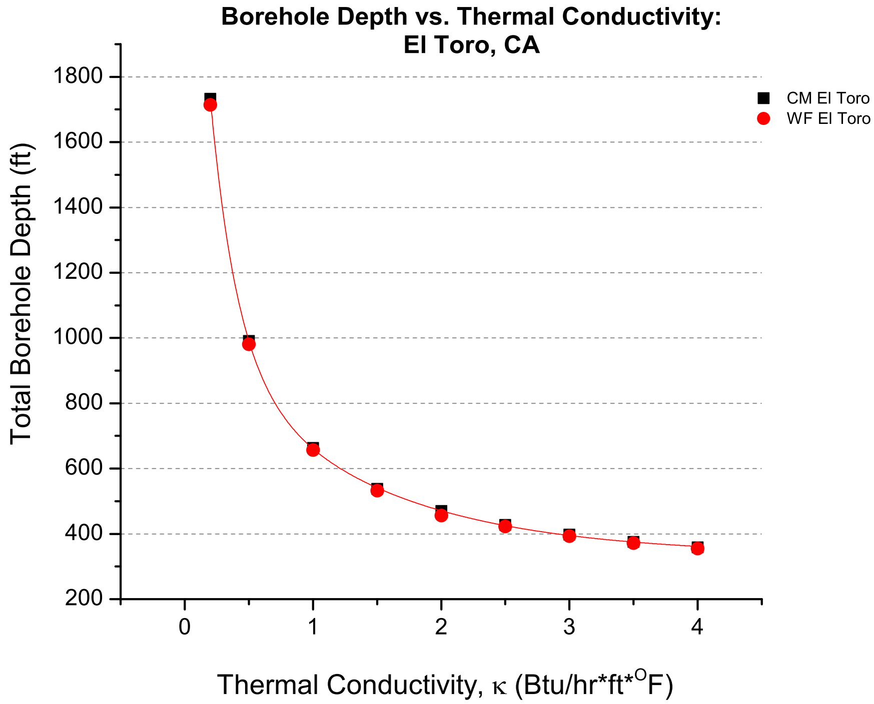


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	2868.1	752	3620.1	761.176	1.051	0.520

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	1611	3048.066	4659.066
CO_2	Kg	338.735	571.695	910.430
SO_2	Kg	0.468	0.003	0.471
NO_x	Kg	0.232	0.519	0.751
SUMS	Kg	339.434	572.217	911.652

California Climate Zone 9

Representative City: Pasadena, CA

Description of Climate Zone

Coastal and interior weather influence this Southern Californian inland valley climate zone. The inland winds bring hot and dry air and the ocean air brings cool moist air. The summers are hot and the winters never frost. Compared to the coast, the summers are warmer and the winters colder.

Comparison of the HDD and CDD indicates that this climate zone is not dominated by either heating or cooling demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD degree days for Climate Zone 9.

	Value	Base (°F)
Heating Degree Days	1460	65
Cooling Degree Days	1455.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 3. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Pasadena.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	
Heating Loads		
8am-12	kBTU/hr	18.9
12-4pm	kBTU/hr	9.4
4pm-8pm	kBTU/hr	4.7
8pm-8am	kBTU/hr	9.4
Annual Equivalent Full-Load Hours	Hours	741
Cooling Loads		
8am-12	kBTU/hr	9.4
12-4pm	kBTU/hr	18.9
4pm-8pm	kBTU/hr	37.7
8pm-8am	kBTU/hr	18.9
Annual Equivalent Full-Load Hours	Hours	1230

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	38.8/33.3
Power (cool/heat)	kW	3.35/2.74
EER/COP (cool/heat)		11.6/3.6
Flow (cool/heat)	gpm	9.4/4.7
Partial Load Factor (cool/heat)		.97/.57

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity is between 0.8 and 2.0.

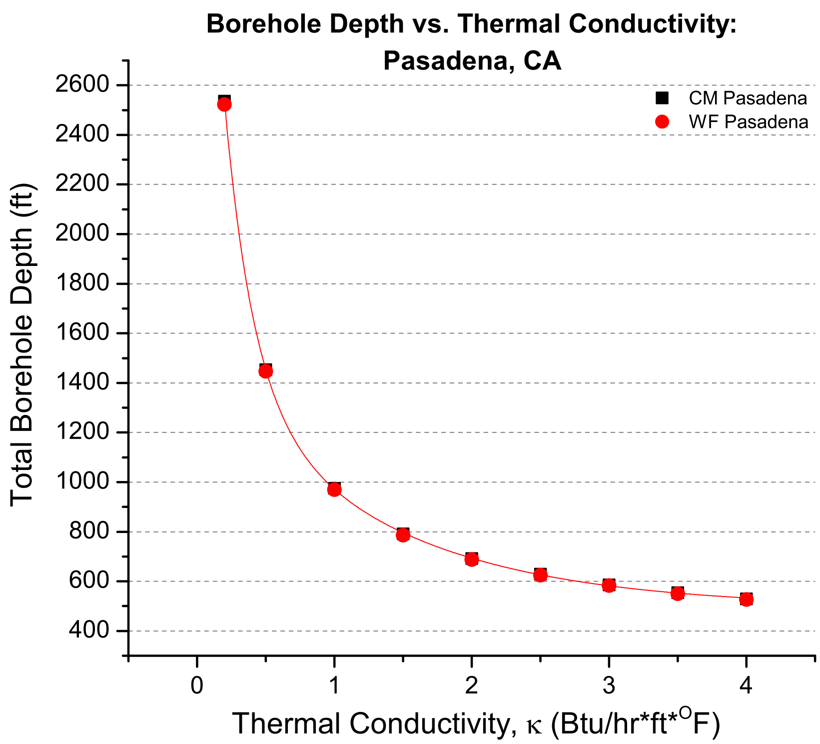


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	4102.9	1205.2	5308.1	1116.102	1.541	0.763

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	2470	5128.9566	7598.957
CO2	Kg	519.352	961.987	1481.339
SO2	Kg	0.717	0.005	0.722
NOx	Kg	0.355	0.873	1.228
SUMS	Kg	520.424	962.865	1483.290

California Climate Zone 10

Representative City: Riverside, CA

Description of Climate Zone

Interior valleys compose the majority of this climate zone. Hilltops and valleys get colder during the winter (possibility of frost) and warmer during the summer. The days are sunny with most of the rain falling in the winter. The summers are hotter, and the winters are colder than the coastal climates. Cooling and heating is necessary.

Comparison of the HDD and CDD indicates that this climate zone is dominated slightly heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 10.

	Value	Base (°F)
Heating Degree Days	1685.25	65
Cooling Degree Days	1619.50	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Riverside.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	
Heating Loads		
8am-12	kBTU/hr	24.041
12-4pm	kBTU/hr	12.0205
4pm-8pm	kBTU/hr	6.01025
8pm-8am	kBTU/hr	12.0205
Annual Equivalent Full-Load Hours	Hours	707.13
Cooling Loads		
8am-12	kBTU/hr	8.62
12-4pm	kBTU/hr	17.24
4pm-8pm	kBTU/hr	34.48
8pm-8am	kBTU/hr	17.24
Annual Equivalent Full-Load Hours	Hours	1308.00

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	38.7/33.8
Power (cool/heat)	kW	3.38/2.76
EER/COP (cool/heat)		11.4/3.6
Flow (cool/heat)	gpm	8.6/6
Partial Load Factor (cool/heat)		.89/.71

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

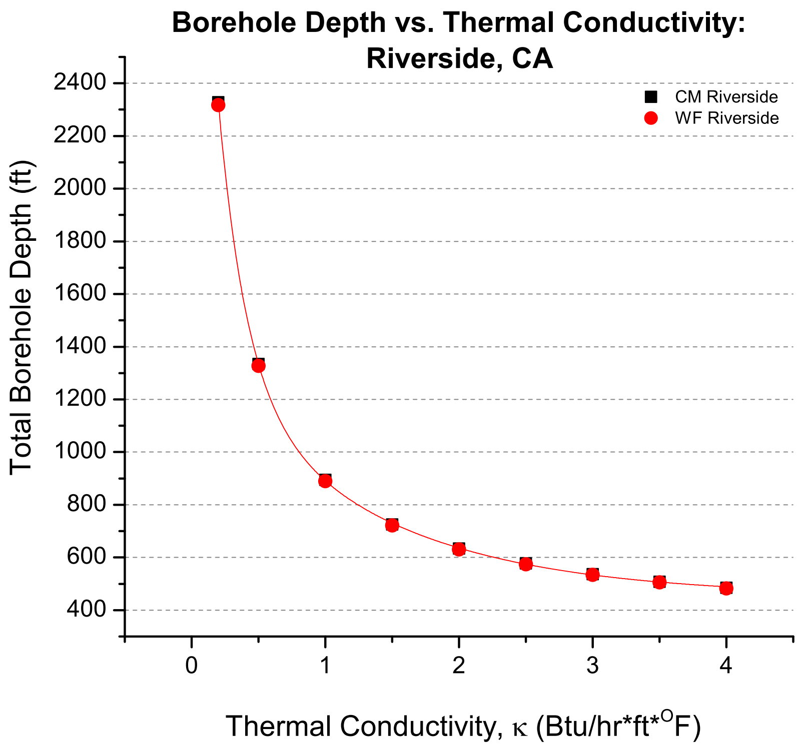


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	4066.8	1443.4	5510.2	1158.596	1.600	0.792

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	2450	6242.6729	8692.673
CO2	Kg	515.147	1170.876	1686.022
SO2	Kg	0.711	0.006	0.717
NOx	Kg	0.352	1.063	1.415
SUMS	Kg	516.210	1171.945	1688.155

California Climate Zone 11

Representative City: Red Bluff, CA

Description of Climate Zone

Climate Zone 11 is in northern California. The seasons are sharply defined with high summer daytime temperatures and very cold winters. During the summer the sun is almost always shining, and during the winter, cold winds from the north bring the possibility of snow and thick Tule fog.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 11.

	Value	Base (°F)
Heating Degree Days	3148.50	65
Cooling Degree Days	1353.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Red Bluff.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	

Heating Loads		
8am-12	kBTU/hr	23.65
12-4pm	kBTU/hr	11.825
4pm-8pm	kBTU/hr	5.9125
8pm-8am	kBTU/hr	11.825
Annual Equivalent Full-Load Hours	Hours	1484.14
Cooling Loads		
8am-12	kBTU/hr	10.04675
12-4pm	kBTU/hr	20.0935
4pm-8pm	kBTU/hr	40.187
8pm-8am	kBTU/hr	20.0935
Annual Equivalent Full-Load Hours	Hours	1368.60

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	46.5/38.7
Power (cool/heat)	kW	3.93/3.23
EER/COP (cool/heat)		11.8/3.5
Flow (cool/heat)	gpm	10/5.9
Partial Load Factor (cool/heat)		.86/.61

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

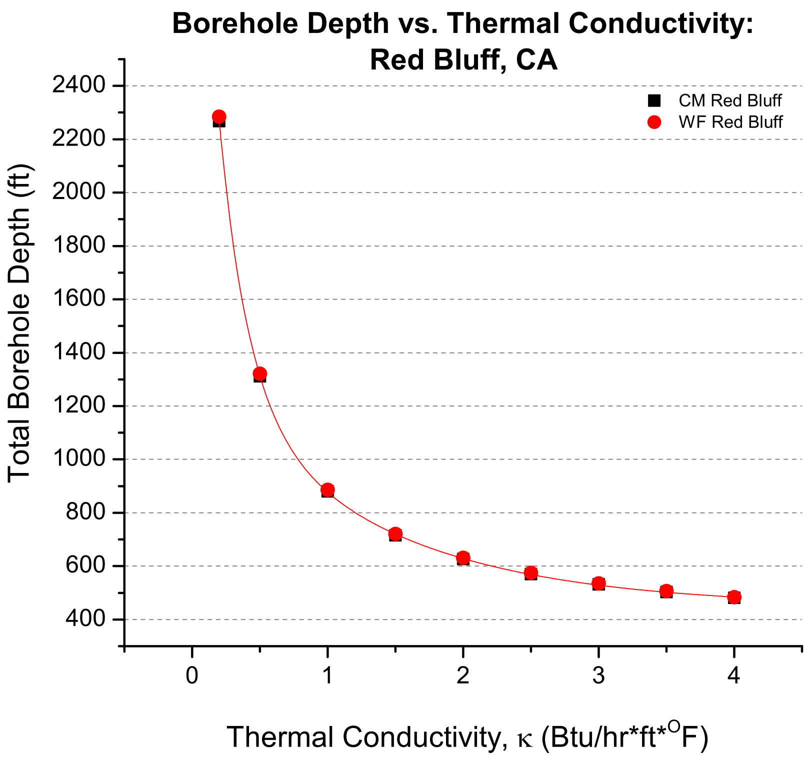


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)
Climate	4777.3	3068.1	7845.4	1649.604	2.278	1.128

Master						

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	**Cooling**	**Heating**	**Total**
Yearly Energy	kWh/yr	3101	12866.3540	15967.354
CO2	Kg	652.028	2413.213	3065.242
SO2	Kg	0.900	0.012	0.913
NOx	Kg	0.446	2.191	2.637
SUMS	Kg	653.375	2415.417	3068.791

California Climate Zone 12

Representative City: Sacramento, CA

Description of Climate Zone

This climate zone is located in the Northern California Central Valley and is situated just inland from the Bay Area. The climate in the Northern Central Valley is characterized by wet winters with mild to moderate cold and hot summers. There is almost no snowfall in the area.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 12.

	Value	Base (°F)
Heating Degree Days	2621.25	65
Cooling Degree Days	1225.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Sacramento.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	

Heating Loads		
8am-12	kBTU/hr	23.888
12-4pm	kBTU/hr	11.944
4pm-8pm	kBTU/hr	5.972
8pm-8am	kBTU/hr	11.944
Annual Equivalent Full-Load Hours	Hours	1402.38
Cooling Loads		
8am-12	kBTU/hr	9.344
12-4pm	kBTU/hr	18.688
4pm-8pm	kBTU/hr	37.376
8pm-8am	kBTU/hr	18.688
Annual Equivalent Full-Load Hours	Hours	1195.95

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	38.8/33.7
Power (cool/heat)	kW	3.35/2.76
EER/COP (cool/heat)		11.6/3.6
Flow (cool/heat)	gpm	9.3/6
Partial Load Factor (cool/heat)		.96/.71

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

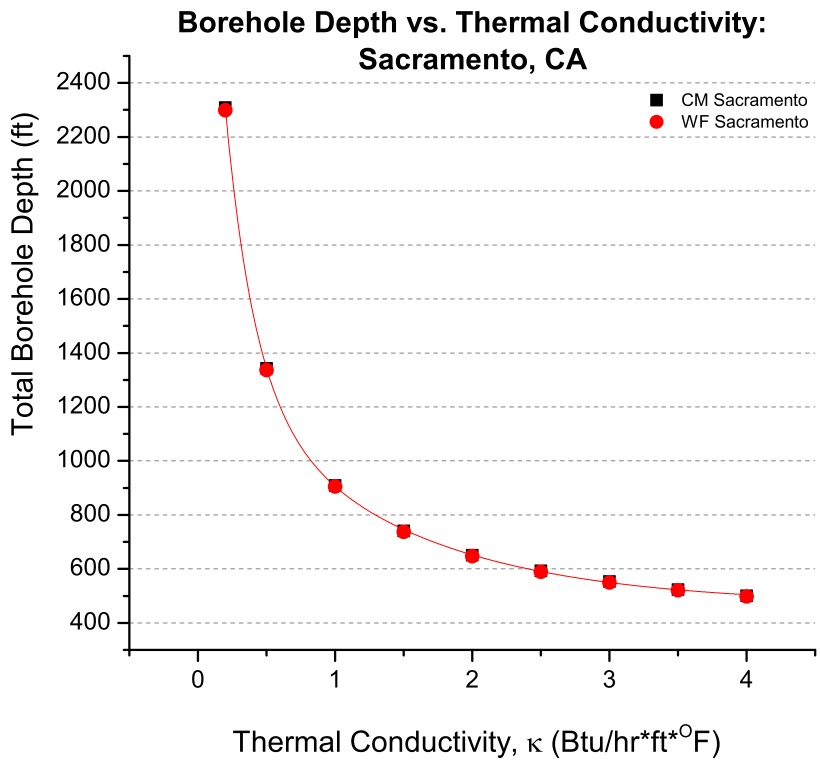


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO_2 (Total)	kg SO_2 (Total)	kg NOx (Total)

Climate Master	3961	2844.1	6805.1	1430.867	1.976	0.978

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	2456	12250.879	14706.879
CO2	Kg	516.408	2297.775	2814.183
SO2	Kg	0.713	0.012	0.725
NOx	Kg	0.353	2.086	2.439
SUMS	Kg	517.474	2299.873	2817.347

California Climate Zone 13

Representative City: Fresno, CA

Description of Climate Zone

This climate zone is located in California's Central Valley. The summer daytime temperatures are high with almost constant sunshine. The summer humidity is higher than in other parts of the Central Valley; this makes energy consumption for cooling much higher in comparison. Winter rains fall between November and April. The winters can be intense, and piercing north winds can blow for days at a time. Persistent Tule fog is a common occurrence during the winter months.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD degree days for Climate Zone 13.

	Value	Base (°F)
Heating Degree Days	2443.25	65
Cooling Degree Days	1599	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Fresno.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	
Heating Loads		
8am-12	kBTU/hr	27.871
12-4pm	kBTU/hr	13.9355
4pm-8pm	kBTU/hr	6.96775
8pm-8am	kBTU/hr	13.9355
Annual Equivalent Full-Load Hours	Hours	1004.63
Cooling Loads		
8am-12	kBTU/hr	10.547
12-4pm	kBTU/hr	21.094
4pm-8pm	kBTU/hr	42.188
8pm-8am	kBTU/hr	21.094
Annual Equivalent Full-Load Hours	Hours	1479.09

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	46.7/39
Power (cool/heat)	kW	3.91/3.25
EER/COP (cool/heat)		11.9/3.5
Flow (cool/heat)	gpm	10.5/7
Partial Load Factor (cool/heat)		.9/.71

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

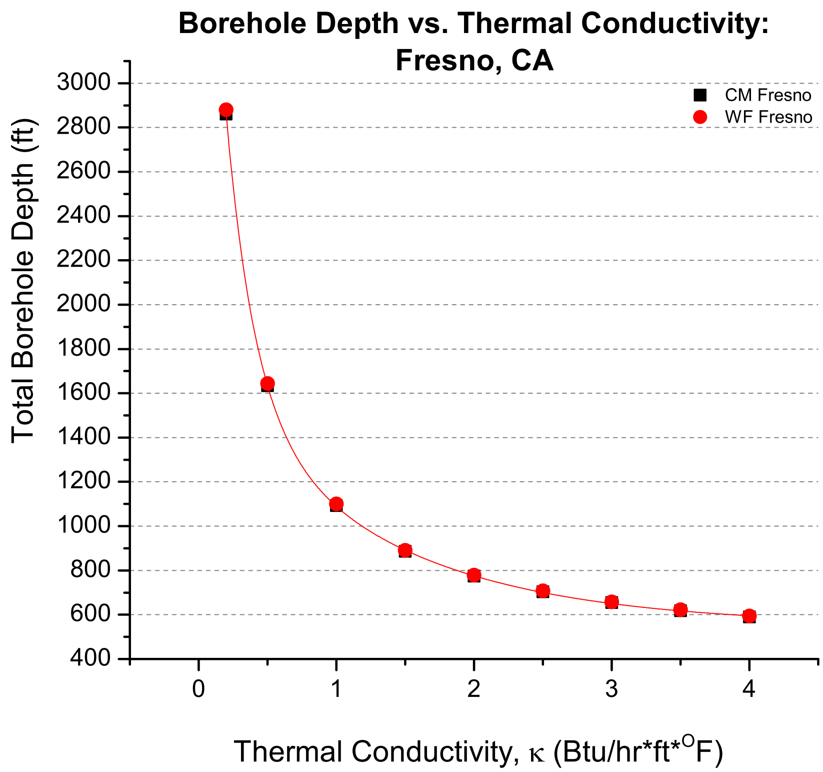


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	5354.7	2420.7	7775.4	1634.886	2.258	1.118

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	3513	10257.9132	13770.913
CO2	Kg	738.657	1923.974	2662.631
SO2	Kg	1.020	0.010	1.030
NOx	Kg	0.505	1.747	2.252
SUMS	Kg	740.182	1925.731	2665.913

California Climate Zone 14

Representative City: China Lake, CA

Description of Climate Zone

This climate zone is medium to high desert. The climate is characterized by large swings in both in summer and winter temperature. Summers are hot and dry. Hot summer days are followed by cool nights. Winters are cold, especially on the slopes and hillsides.

Comparison of the HDD and CDD indicates that this climate zone is dominated by cooling demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD) degree days for Climate Zone 14.

	Value	Base (°F)
Heating Degree Days	2421.75	65
Cooling Degree Days	3055.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	

Heating Loads		
8am-12	kBTU/hr	33.536
12-4pm	kBTU/hr	16.768
4pm-8pm	kBTU/hr	8.384
8pm-8am	kBTU/hr	16.768
Annual Equivalent Full-Load Hours	Hours	954.20
Cooling Loads		
8am-12	kBTU/hr	10.37125
12-4pm	kBTU/hr	20.7425
4pm-8pm	kBTU/hr	41.485
8pm-8am	kBTU/hr	20.7425
Annual Equivalent Full-Load Hours	Hours	1844.04

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	46.6/39.5
Power (cool/heat)	kW	3.92/3.28
EER/COP (cool/heat)		11.9/3.5
Flow (cool/heat)	gpm	10.4/8.4
Partial Load Factor (cool/heat)		.89/.85

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

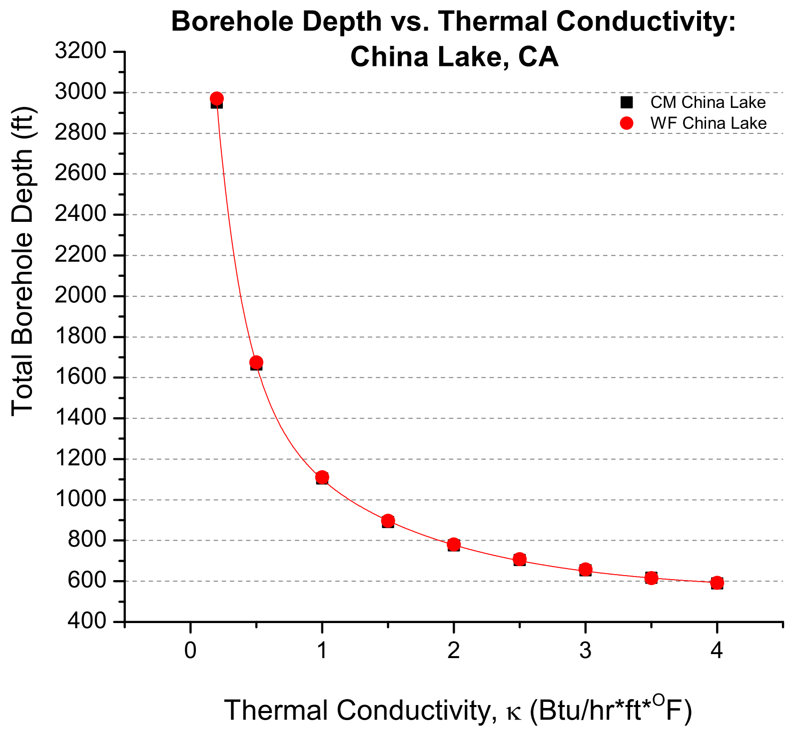


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	6585.4	2733.5	9318.9	1959.428	2.706	1.340

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	**Cooling**	**Heating**	**Total**
Yearly Energy	kWh/yr	4438	11723.3294	16161.329
CO2	Kg	933.151	2198.828	3131.979
SO2	Kg	1.289	0.011	1.300
NOx	Kg	0.638	1.996	2.634
SUMS	Kg	935.078	2200.835	3135.913

California Climate Zone 15

Representative City: El Centro, CA

Description of Climate Zone

This climate zone is best described as a low desert and is characterized by extremely hot and dry summers with moderately cold winters. The humidity in the area is low compared to the rest of California resulting in large temperature swings from day to night. Summer storms bring most of the annual rainfall. The winters are short and mild and can sometimes bring short frosts.

Comparison of the HDD and CDD indicates that this climate zone is dominated by cooling demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD degree days for Climate Zone 15.

	Value	Base (°F)
Heating Degree Days	1177	65
Cooling Degree Days	4759.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in El Centro.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	
Heating Loads		
8am-12	kBTU/hr	18.647
12-4pm	kBTU/hr	9.3235
4pm-8pm	kBTU/hr	4.66175
8pm-8am	kBTU/hr	9.3235
Annual Equivalent Full-Load Hours	Hours	461.20
Cooling Loads		
8am-12	kBTU/hr	11.638
12-4pm	kBTU/hr	23.276
4pm-8pm	kBTU/hr	46.552
8pm-8am	kBTU/hr	23.276
Annual Equivalent Full-Load Hours	Hours	2515.47

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	47/38.3
Power (cool/heat)	kW	3.87/3.21
EER/COP (cool/heat)		12.1/3.5
Flow (cool/heat)	gpm	11.6/4.7
Partial Load Factor (cool/heat)		.99/.49

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity values is between 0.8 and 2.0.

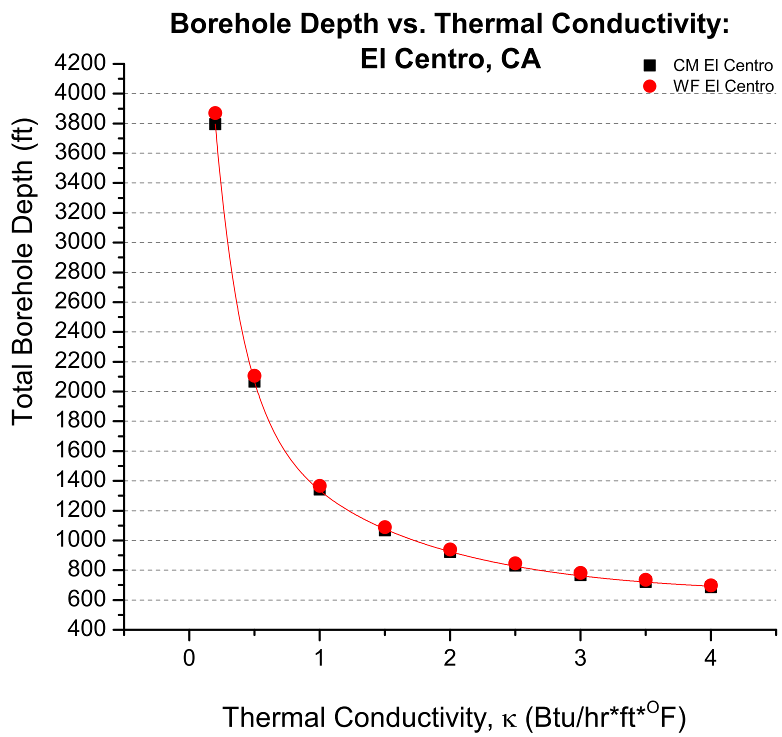


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)

Climate Master	9894.3	756.6	10650.9	2239.500	3.093	1.531

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	Cooling	Heating	Total
Yearly Energy	kWh/yr	6982	3165.2989	10147.299
CO2	Kg	1468.062	593.683	2061.746
SO2	Kg	2.027	0.003	2.030
NOx	Kg	1.004	0.539	1.543
SUMS	Kg	1471.094	594.226	2065.319

California Climate Zone 16

Representative City: Mount Shasta, CA

Description of Climate Zone

Climate Zone 16 is a high (above 5,000 ft), mountainous, semi-arid region. The climate is mostly cold, but seasonal changes are well defined and summer temperatures can be mild. Cool temperatures and snow cover are present for more than half the year. Summer temperatures tend to be moderate but the nights can be cool.

Comparison of the HDD and CDD indicates that this climate zone is dominated by heating demand, as shown in Table 1.

Table 1. Heating (HDD) and cooling (CDD degree days for Climate Zone 16.

	Value	Base (°F)
Heating Degree Days	5056.75	65
Cooling Degree Days	595.75	80

Values from Pacific energy Center's Guide to California Climate Zones. The values are averaged from four cities across the entire climate zone

The heating and cooling load schedule derived from the ESim software to calculate the loop design are given in Table 2. The blue and green highlighted values represent the maximum and minimum load values (respectively) for the simulated house in Mount Shasta.

Table 2. Heating and cooling load schedule and AEFLH used in GLD.

PARAMETER	UNIT	

Heating Loads		
8am-12	kBTU/hr	26.409
12-4pm	kBTU/hr	13.2045
4pm-8pm	kBTU/hr	6.60225
8pm-8am	kBTU/hr	13.2045
Annual Equivalent Full-Load Hours	Hours	1287.44
Cooling Loads		
8am-12	kBTU/hr	9.12225
12-4pm	kBTU/hr	18.2445
4pm-8pm	kBTU/hr	36.489
8pm-8am	kBTU/hr	18.2445
Annual Equivalent Full-Load Hours	Hours	1471.68

The parameters used in the GLD software to calculate loop properties are given in Table 3. For comparison purposes, simulations were done using two different pumps from different manufacturers, selected at random, in order to illustrate the effects on loop design of pump properties. The results from both are shown in Figure 1. Results from other manufacturers of pumps provide similar results.

Table 3. Loop design parameters that were used in GLD in conjunction with the heating and cooling load schedule and AEFLH given in Table 2.

PARAMETER	UNIT	Climate Master
Pump		
Model		GR Vertical
Capacity (cool/heat)	kBTU/hr	38.8/34
Power (cool/heat)	kW	3.36/2.77
EER/COP (cool/heat)		11.5/3.6
Flow (cool/heat)	gpm	9.1/6.6
Partial Load Factor (cool/heat)		.94/.78

The resulting borehole length, as a function of soil thermal conductivity is given in Figure 1. The likely range of thermal conductivity is between 0.8 and 2.0.

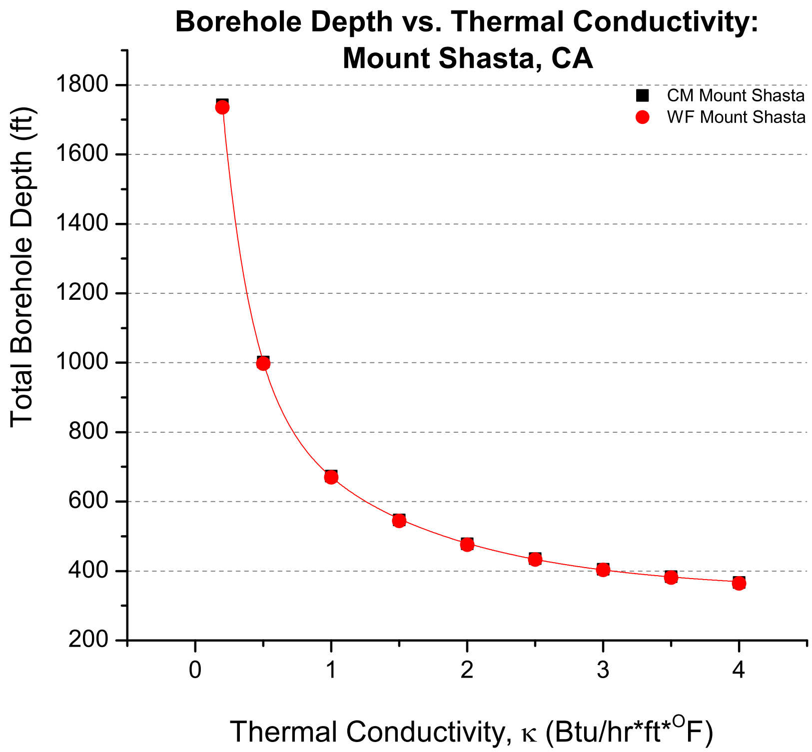


Figure 1. Graph displaying the change in borehole depth with respect to thermal conductivity of the soil. CM=Climate Master; WF = Water Furnace.

Greenhouse gas emissions: HVAC vs. GHP

The energy demands and emission values for a GHP system installed in the reference design residence in this climate zone are given in Table 4. The comparable values for a conventional HVAC system are given in Table 5. Significant reductions in energy use and total emissions would result from installation of a GHP system.

Table 4. Energy and Emission Values for Cooling and Heating from GHP

Pump Brand	Yearly Electricity (Cooling) [kWh/yr]	Yearly Electricity (Heating) [kWh/yr]	Yearly Electricity (Total) [kWh/yr]	kg CO2 (Total)	kg SO2 (Total)	kg NOx (Total)
Climate	4794	2872.8	7666.8	1612.051	2.226	1.102

Master						

Table 5. Electricity and Natural Gas Emission Values for Conventional HVAC Systems

	Unit	**Cooling**	**Heating**	**Total**
Yearly Energy	kWh/yr	3025	12485.3458	15510.346
CO2	Kg	636.048	2341.751	2977.800
SO2	Kg	0.878	0.012	0.890
NOx	Kg	0.435	2.126	2.561
SUMS	Kg	637.361	2343.890	2981.251