Geothermal Academy
Focus Center for Data Collection, Analysis and Dissemination

Final Project Report
October 2011

Recovery Act – Geothermal Technologies Program:

Ground Source Heat Pumps

DE-FOA-0000116
CFDA Number: 81.087

U.S. Department of Energy
Golden Field Office
Mail Stop 1501
1617 Cole Boulevard
Golden, Colorado 80401
Contact person: Pete Simon
E-mail: FY09EGSResearch@go.doe.gov

Submitted By

Masami Nakagawa
Colorado School of Mines
1500 Illinois Street, Golden, Colorado 80401

Summary Table of Contents

Geothermal Academy:

A Pathway for Confirmation of Ground-Source Heat Pumps in the United States

Masami Nakagawa, Adam Reed, Hendro Fujiono, and John S. McCartney

In 2008, Oak Ridge National Laboratory issued a report on geothermal heat pumps (GHPs) focused on the market status, barriers to adoption, and actions to overcome these barriers (Hughes 2008). Of the barriers raised in this report, of the most pressing is a lack of performance and energy usage data for GHPs. Further, an associated barrier is a lack of a fair comparison of the energy usage of conventional heating and cooling systems for the same building. Because of these barriers, we are not able to say how much energy is used by well-designed GHP systems on a long-term basis, nor are we able to say how better their energy usage is compared to conventional systems. The need for a fair comparison with conventional systems is particularly relevant as modern versions of conventional air conditioners, gas furnaces, and boilers have also incorporated energy saving technologies.

As a first step to address this barrier, the Geothermal Academy has developed a framework for data collection. This framework has already been applied to several geothermal installations in Colorado (Nakagawa et al. 2010). The framework classifies data into different categories based on the relevance of the data to understanding the energy consumption of a GHP system. The first category is direct energy consumption data. The advantage of collecting this type of data is that it is the main piece of information required to assess the performance of the GHP. However, an issue with only collecting the direct energy consumption is that we may be at a loss to explain the trends in energy consumption should the system show poor efficiency. Specifically, the GHP system may be under-designed to meet the energy loads of the building, so only collecting the energy consumption may paint an unfair picture about the energy usage of GHP systems in general. Accordingly, the second category is heat exchange performance data. This includes the measured entering/exiting water temperatures and circulation rates for the heat pump over time. The temperature data permits interpretation of the thermal energy being transferred to or from the ground. Combined with the energy consumption, this information also permits quantification of the coefficient of performance, an industry accepted metric equal to the ratio of thermal energy delivered divided by the electrical energy required to operate the system. The circulation rate indicates viscosity changes in the heat exchange fluid and may reveal leaks. A third category of data includes GHP design parameters. These include data specific to the GHP itself, including the GHP unit type and capacity, the length, dimension, and configuration (vertical or horizontal) of the heat exchangers embedded in the ground, as well as data specific to the climate setting (maximum and minimum air temperatures and relative humidity), and data specific to the building (design heating and cooling load patterns throughout the year). If the design data for a GHP system is known, then the actual performance metrics of the system may be simulated using commercially-available software such as eQuest or GLHEPro.

The main recommendation of this project is to include a minimal data collection system on each heat pump installed in the United States, capable of measuring the electrical energy consumed, the entering/exiting fluid temperatures, and circulation rates. This is a viable and cost effective solution which will provide performance data because data collection systems are only a fraction of the cost of a GHP unit, and because modern GHP units already incorporate sensors to monitor energy usage and the entering and exiting fluid temperatures. Specifically, these sensors are used to control the GHP unit to provide the heat exchange required to provide a desired temperature within a building. Accordingly, it is straightforward for this operational data to be collected to start building a database of GHP performance such that can provide statistically relevant comparison with other heating and cooling systems. In addition to collecting the data, such a system could be easily implemented with a wireless transmitter so that data could be sent to a home PC where it could be transmitted to a central database at NREL. Display of the data on a user's PC would provide feedback on the performance of their system which could perhaps refine their use of the system to reach their personal energy goals.

Although a system such as that described above has yet to be incorporated directly into commercial GHP systems, it is straightforward and inexpensive to outfit a GHP with a data acquisition system and supplemental sensors. A secondary recommendation is to consider funding a pilot effort that will collect the energy and performance time series data from a representative sample of installations. A preliminary pilot effort was undertaken by the Geothermal Academy at Kinard Middle School, in Ft. Collins, Colorado, which demonstrated the feasibility and ease of such an effort. A full-scale pilot effort could be implemented rather easily by building upon the relationships developed as part of the formation of the Geothermal Academy. A full-scale pilot effort would be most suited to evaluate the performance of GHP installations in different climate settings, preferably focusing on residential, commercial, and public buildings. If a full-scale pilot effort were to be undertaken, it is recommended to also identify large buildings which may incorporate a back-up conventional heating and cooling system in order to provide statistically relevant comparison data to assess the improvement in GHP energy usage over other heating and cooling technologies.

Such a data collection system would provide several benefits to the different sectors of society which are concerned with GHP technology and implementation. A summary of the benefits for each sector are summarized below:

Consumers

- Routine free "health" diagnostics
- Prevention of an expensive damage/repair
- Contributing towards saving energy and reducing GHG emission; the "makes me feel good" effect
- Reduce monthly electricity bill

Installers

- Rapid increase of sales due to gained confidence of consumers
- Long-term customer care service to strengthen a trusting relationship
- Provide a comprehensive history of an installed unit, providing better diagnostics and repair strategies
- Elimination of unqualified installers

Policy Makers

- Statistically relevant data which could be used to justify policy decisions.
- Information on the benefits of tax credits and other implementation strategies.

Geothermal Academy and GHP Researchers

- Can use archived time series data to validate theories that many simulation tools are based on
- Provide further opportunities for research on climate change issues in collaboration with the National Geothermal Data Systems
- Opportunity to develop iPhone and other smart phone applications to promote consumer awareness
- Can study an exciting area of economics called "the virtual economy"
- Opportunity to study how the consumer behaves when a new technology is introduced
- Research how the collected data can be used to influence policy makers

Utility Companies and Government Regulators

- Real-time monitoring will provide utility companies with feedback on peak loads - there is growing concern about the fact that aging grids may not be able to handle electricity from peak solar power
- Minimizing GHG consumption

References:

Hughes, P.J. 2008. Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers. Oak Ridge National Laboratory Report ONRL-2008/232.

Nakagawa, M., Reed, A., Fujioni, H., and McCartney, J.S. (2010). A Comprehensive and Integrated Framework for Data Collection and Triple Bottom Line Analysis of Geothermal Heat Pump Systems. Report to the Department of Energy.

Data Collection Framework and Performance Analysis for Geothermal Heat Pump Systems

Masami Nakagawa,[1] Adam Reed,[2] Hendro Fujiono[3], and John S. McCartney[4]

TABLE OF CONTENTS

[1] Ph.D., Colorado School of Mines/NREL Joint Appointee for Geothermal; Senior Geothermal Scientist.
[2] J.D., Esq., Research Fellow, Center for Energy and Environmental Security, Univ. of Colorado, Boulder.
[3] Ph.D. Candidate, Colorado School of Mines, Department of Mining Engineering.
[4] Ph.D., PE, Assistant Professor, Civil Engineering, University of Colorado at Boulder.

1. FOREWORD

Geothermal heat pump (GHP) systems[4] offer the potential for significant reductions in the amount of energy used for space conditioning--the heating and cooling of our homes, schools, offices, and facilities. Distinguishable from deep geothermal resources that draw upon hydrothermal or hot rock resources for direct heating or production of electricity, GHPs operate at relatively shallow depths, can be used nearly anywhere, and do not produce electricity. Rather, a GHP system uses the temperature differential between the ground and a fluid circulating through loops underneath a structure to dramatically improve the efficiency of a heat pump, reducing energy use for space conditioning and water heating by up to 75%, depending on the typical heating/cooling system used in a climatic region.[5]

The operation of a GHP system takes advantage of the relatively stable temperatures in the first 100 meters of subsurface as a heat sink or heat source (depending on whether the system is operating in heating or cooling mode) through a clever utilization of the laws of thermodynamics. A GHP installation may be thought of as three loops that comprise a system to move heat from the ground into a building:

1. Ground source loop
2. Refrigeration loop
3. Load loop (to the building space to be conditioned)

The ground source loop may either be a closed or open loop. A closed ground loop heat exchanger involves circulation of a water or water/antifreeze solution in plastic tubing embedded in the ground or in a pond. The industry standard for the closed ground loop tubing used in GHP is high-density polyethylene (HDPE) tubing, which often has a 50 year warranty. An open loop involves extraction of groundwater from a well, circulation through a heat exchanger, and recharging of the water to its source. The refrigeration loop within the heat pump unit involves changing the phase of a refrigerant substance from liquid to superheated gas in order to exchange heat between the ground loop and the load loop. The load loop may also be contained within the heat pump (unless it is a split system), and involves a refrigerant-to-air or refrigerant-to-water coil which transfers heated or cooled air or water to the delivery system in the building. The delivery system may be a conventional air duct system or a hydronic system.

An example of a closed-loop geothermal heat pump system is shown in Figure 1. In heating mode, low-temperature water or antifreeze is circulated through the ground loops, which absorbs heat from the ground by conduction. When the water, carrying heat from the ground, returns to the heat exchanger coupling in the lower right hand corner of the figure it exchanges heat with the refrigerant in the heat pump. The heat pump then compresses the refrigerant, raising its temperature and converting it to a superheated vapor. This superheated vapor is used to heat water or air in the structure. The gaseous refrigerant, now lower in temperature due to the thermal exchange with the home water or air systems, then enters an expansion chamber where

[4] Geothermal heat pump systems are also referred to interchangeably as ground-source heat pump systems, geoexchange systems, and geo-heat exchangers. All terms refer to the same technology.
[5] See Hughes, P.J. Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers, Oak Ridge National Laboratory, Report ONRL-2008/232. December 2008, (citing DOE 2007. Buildings Energy Data Book. http://buildingsdatabook.eren.doe.gov/)

pressure is released and temperature drops yet again, converting the gaseous refrigerant back to a low-temperature liquid. In cooling mode, the cycle is simply reversed.

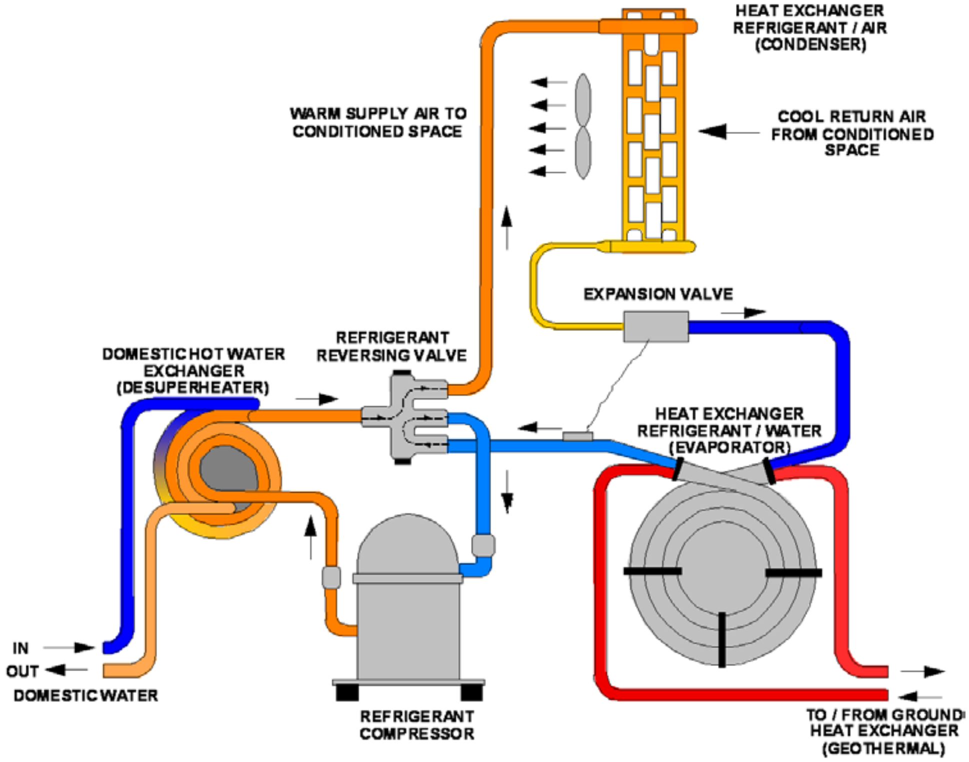

Figure 1 -- A schematic of a Geothermal Heat Pump System

The key component of a ground-source heat pump system is the heat exchanger coupling which transfers heat from water or antifreeze circulating in the ground heat exchanger and the refrigerant in the heat pump loop. A typical water-to-refrigerant coaxial heat exchanger coupling found within a heat pump is shown in Figure 2. The water or antifreeze circulates in the inner tube while refrigerant circulates in the outer annulus.

(a) (b)

Figure 2 – Heat exchanger coupling linking ground loop and refrigerant loop: (a) Profile; (b) Cross-section

All GHP systems use a heat exchanger loop embedded in a borehole, trench, civil engineering structure, or water source to absorb heat from the subsurface when the heat pump is in heating mode, and to reject heat to the subsurface when the heat pump is in cooling mode. GHPs can be designed using three main types of heat exchanger configurations. The first involves transfer of heat from the heat exchange loop by conduction to the ground, referred to as a ground-coupled heat pump (GCHP), the second exchanges heat with the groundwater, referred to as a groundwater heat pump (GWHP), and the third exchanges heat with surface water such as ponds or lakes, referred to as a surface water heat pump (SWHP)[6]. Different configurations of heat exchangers in GHP systems are shown in Figure 3 (vertical loops, horizontal trench loops, slinky loops, and pond loops). The type of loop configuration selected for a given building will depend on the geological profile, thermogeologic properties, hydrogeology, climatic and geographic conditions at the location of the building, and the building's heating/cooling load pattern throughout the year. Although GHPs can function effectively in any climate, the choice of the appropriate type of system will depend on surface land availability and local regulations for ground/surface water usage.

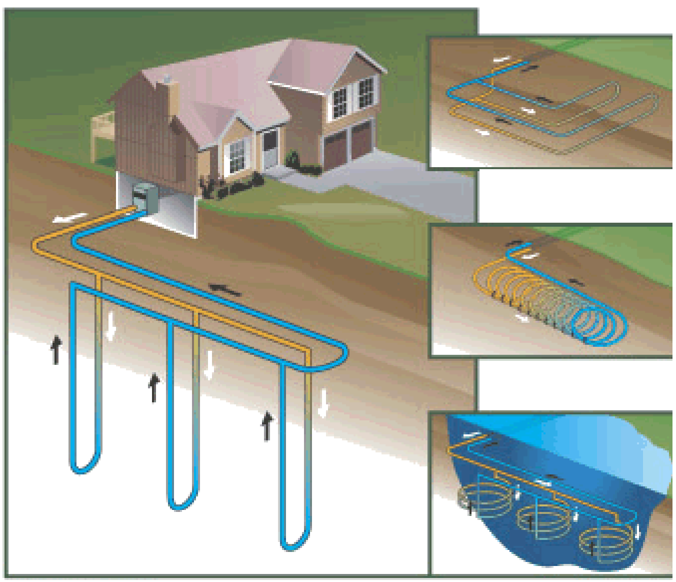

Figure 3 -- GHP loop configurations (after geosyndicate.com): (a) Vertical loops; (b) Horizontal trench loops; (c) Slinky loops; (d) Pond loops

GCHPs are typically referred to as closed loop systems because a fluid is circulated in the heat exchanger loop and never comes in direct contact with the ground or groundwater. Closed-loop systems operate primarily using conduction as a heat transfer mechanism. Accordingly, the length of heat exchanger embedded within the ground is the key design parameter. The most widely-used GCHP systems involve circulation of a heat exchanger fluid (typically a water-antifreeze solution) through a closed-loop series of plastic (polyethylene) pipes embedded in the ground vertically in boreholes or horizontally in trenches. Heat is exchanged between the ground and this loop by conduction, and heat is exchanged between the circulating fluid and the heat loop material by convection. GCHPs have also been designed so that the refrigerant within the heat pump is circulated directly within the heat exchange loop embedded in the ground. This type of GCHP is known as a direct expansion GCHP system (DX-GCHP). DX-GCHP systems

[6] Based on the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) nomenclature. *See* Stephen P. Kavanaugh and Kevin Rafferty, *Ground Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. – Atlanta, Georgia, (1997) .

typically use copper tubing as the heat exchanger. These systems are not in wide use in the United States because of risks associated with leakage of refrigerant into the groundwater.

GWHPs are typically referred to as open loop systems, because they actively pump groundwater into a heat exchanger loop, after which it is re-injected into its original location. Different from GCHPs, the primary heat transfer mechanism in GWHP is convection of water pumped from the ground past a heat exchanger. The groundwater can be used directly in the heat pump or pumped to a water-to-water plate heat exchanger.[7] Accordingly, the capacity of a GWHP to absorb or reject heat depends on the temperature difference between the heat exchanger and the groundwater, the groundwater flux within the ground (i.e., the rate at which warm groundwater is replenished at a given location in the ground), the pumping rate, and the groundwater heat capacity.[8] The heat-exchanger loops in this system are configured vertically, through wells that access the aquifer. The used water then maybe re-injected or sent to a nearby surface water body (lakes or ponds). The GWHP system offers a lower capital cost[9] and higher coefficient of performance[10] wherever it is feasible. The feasibility of using a groundwater system depends on the availability of groundwater and local regulations concerning ground/surface water usage. A GWHP system design must consider hydrogeology factors (i.e. hydraulic conductivity, aquifer hydraulic properties) because this system extracts ground water from the aquifer.

A SWHP can be an open or closed-loop system. The closed-loop SWHP system is similar to the GCHP system, while the open loop SWHP system is similar to the GWHP system. The difference in both cases is the use of surface water, such as water from lakes or ponds, as the heat transfer medium.

The efficiency of a heat pump system depends on the difference between the target temperature within the building and the temperature of the heat source or sink in the building, as this temperature differential will dictate the operation of the compressor. Accordingly, the efficiency of a GHP can have superior efficiency to conventional air-source heat pumps in some climates because the temperature of the ground is more stable than that of the outside air[11]. The energy efficiency of heat pumps is typically quantified as the coefficient of performance, which is the ratio of the thermal energy output from the system to the required electrical energy for pump operation.

The potential for such large reductions in space conditioning energy use is significant for both national energy security goals as well as the ongoing battle against climate change: the built environment accounts for 72% of total U.S. electrical energy use, 55% of U.S. natural gas

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[7] David D. Vanderburg, "Comparative Energy and Cost Analysis between Conventional HVAC Systems and Geothermal Heat Pump Systems", Master Thesis – Air Force Institute of Technology, Wright-Patterson Air Force Base – Ohio, (2002).
[8] David Banks, *An Introduction to Thermogeology: Ground Source Heating and Cooling*, Blackwell Publishing Ltd., Malden – MA, (2008).
[9] Kevin Rafferty, *A Capital Cost Comparison of Commercial Ground-Source Heat Pump Systems,* Geo-Heat Center Bulletin - February, pp. 7 - 10, (1995).
[10] Karl Oschner, Geothermal Heat Pumps: A Guide for Planning and Installing, Earthscan, VA - USA, (2008).
[11] *See* Omer, A.M. 2008. Ground-source heat pumps systems and applications. Renewable and Sustainable Energy Reviews. 12(2), 344-371.

consumption, and 40% of U.S. greenhouse gas emissions.[12] The Energy Information Agency has estimated potential GHP energy savings at 2.7 quadrillion Btu by 2030.[13]

Despite the promise of GHP systems, the U.S. has yet to see widespread market penetration of the technology. Oak Ridge National Laboratory found a number of reasons for this disparity, including the high capital costs of the system (due to the need to install the loops by drilling or excavation) and the general lack of available, objective data on the true lifecycle costs and benefits of GHP systems.[14] Although installation cost issues are currently being addressed through community installations of heat exchanger loops (DMEA REF) and incorporation of loops into civil engineering structures which are already being installed into the ground[15,16], the lack of performance data is still unaddressed. This lack of available data hampers GHP system market scale-up in a number of critical spaces, both at the system design and installation level and at the policy level.

At the installation level, GHP system designers and installers suffer from uncertainty in the length of heat exchanger loop required to move a sufficient amount of heat from or to the ground, as well as a lack of predictability in the costs of drilling and excavation to the depths required for the loop length. This is because local geological conditions can cause unforeseen difficulties in drilling, especially if hard soils or rock are encountered during drilling. Although there is a wealth of information on drilling experience from water well installation, civil engineering construction, and oil exploration, in most areas of the U.S., this information is typically proprietary. A database of knowledge on drilling and excavation conditions in particular locales based on experience could improve the ability of installers to predict capital costs.

At the design level, the thermal conductivity of the soil—its ability to conduct heat - depends on the soil/rock type and the presence of groundwater. The thermal conductivity is a key parameter in determining the length of loop required to supply the required amount of heating or cooling to a building, so this variability can complicate the loop design process. Designers take spot measurements of thermal conductivity at installation sites in order to determine how to size the system to meet the loads of the structure. The length is typically oversized because of uncertainties in these spot measurements. Depending on the magnitude of uncertainty, the over-sizing may result in an uneconomical estimate of the length of loop required. A database of thermal conductivities at installations in particular locations could improve the ability of designers to evaluate spot measurements of thermal conductivities in corresponding regions. Another design issue which needs clarification is the interaction between the building load and the required length of heat exchanger. A database correlating the coefficients of performance would be useful for designers in evaluating the level of conservatism incorporated into a design.

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[12] *See* Hughes, P.J. *Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers*, Oak Ridge National Laboratory, Report ONRL-2008/232. December 2008, at 3 (citing DOE. 2007. *Buildings Energy Data Book*. http://buildingsdatabook.eren.doe.gov)
[13] *See id*. at 23.
[14] *See id.* at 26.
[15] *See* Brandl, H. (2006). "Energy Foundations and other thermo-active ground structures." Géotechnique. 56(2), 81-122.26.
[16] *See* Adam, D. and Markiewicz, R. (2009). "Energy from earth-coupled structures, foundations, tunnels and sewers." Géotechnique. 59(3), 229–236.

At the policy level, GHP systems are either entirely unknown—dwarfed by the attention lavished on deep geothermal resources—or unproven as to the economic or energy efficiency benefits offered by the systems when compared to conventional space conditioning technologies such as furnaces (natural gas), air conditioners (electric), hot water boilers (natural gas), or air-source heat pumps (electric), and others. Viable policy options exist to drive deployment through consideration of GHP systems in electric utility integrated resource planning as well as demand response/energy efficiency strategies. But legislators, regulators, and utilities alike are reticent to act without knowing the costs and benefits which can be expected from a full-scale deployment of GHP systems. For instance, questions which may be asked include: How will such systems affect system peak loads, customer energy bills, and emissions of greenhouse gases from utility facilities? Will customers like the comfort of GHP systems and take advantage of incentive programs? Without an objective knowledge base to provide answers to these questions, any policy-maker will be nervous about promoting GHPs, lest a large capital investment in the technology fail to yield the expected benefits.

2. INTRODUCTION

Recognizing the need for objective data on GHP system performance identified by Oak Ridge National Laboratory[17], the U.S. Department of Energy's Geothermal Technologies Program funded the Geothermal Academy at the Colorado School of Mines to develop a framework for collecting and analyzing system performance data from geothermal heat pump (GHP) systems. The goal of this year-long project was not to collect vast amounts of GHP system data, but rather to design a conceptual framework for data collection and analysis which could be used by installers, designers, and policy makers to provide objective, relevant, and understandable data on GHP performance. The importance of the required effort in formulating this framework should not be underestimated. Reams of data collected without a coherent strategy for their application in practice will not be sufficient to affect the sea-change in the energy efficiency of space conditioning technologies needed to tackle the energy security and environmental challenges facing the country.

The purpose of this report is to denote a path for transforming individual system-level data into relevant information for policy-makers, who must contend with diverse priorities and mandates in energy and environmental decision-making. Accordingly, the framework presented here *contextualizes* data points and performance metrics for individual GHP systems within a triple bottom line analysis of economic, environmental, and socio-economic costs and benefits, for consumption by policy-makers.

It is important to emphasize at the outset that the framework developed by the Geothermal Academy is explicitly directed toward energy policy concerns rather than building-level decision-making or fundamental research on GHPs. While inclusive of detailed technical data for each system being studied, it is *not* a modeling tool for prospectively sizing and pricing GHP systems—proprietary tools already exist in the private sector. Nor is it an econometric or detailed relational study, attempting to reveal relationships between, say, the composition of the

[17] *See* Hughes, P.J. Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers, Oak Ridge National Laboratory, Report ONRL-2008/232. December 2008

soil in New Mexico and the operating characteristics of an installed GHP system. The framework may readily be expanded for fundamental research at a later date.

In addition to providing reference information for installers, designers, and policy makers, another intention of the framework described in this report is to assist decision-makers at electric utilities, local governments, state public utility commissions, and the Federal Energy Regulatory Commission (FERC)—to name a few—in understanding the potential of GHP technologies to provide energy efficiency and cost-savings, emissions reductions, and better management of electricity system peak loads. Such understanding, backed by empirical evidence, has the potential to influence the development of laws, regulations, and rules at the federal, state, and local government levels which may affect GHP deployment. With the needs of these decision-makers in mind, we aim to provide a pathway for empirically answering the following questions, both for an individual system and for an aggregation of many systems for which data may be collected by a future data collection and analysis system:

1. What cost savings does a GHP system provide to its owner, compared with that for other potential space conditioning technologies?

2. What emissions savings does a GHP system provide to the utility serving the heat pump with electricity, compared to other potential space conditioning technologies?

3. How does a GHP system's daily load profile compare to the utility's daily system load profile, *i.e.*, will the GHP system's load profile provide demand reduction to the utility at times of system peak load, and by how much?

A data collection and analysis program which implements the framework in this document is expected to be capable of providing quantitative and empirical answers to these questions. In turn, this will provide policy-makers at the legislative, regulatory, and internal utility levels with the information they need to make a strong case for pro-GHP system policies.

Constructing effective answers to any of the questions above consists of three steps: (i) identifying the party to be influenced by the data and its needs; (ii) identifying what kinds of data need to be gathered to answer the question; and (iii) identifying the method of analysis to be used to reach an answer. Consequently, the substantive portions of this report are divided into three sections.

First, we examine the relevance of GHP systems to an array of energy policy concerns and decision-makers, from an institutional standpoint. This means that we are interested not only in how a GHP system affects, for example, GHG emissions, but also in how various policy-making bodies concerned with GHG emissions make decisions. In this way, the framework identifies the pathways through which data and analysis must travel in order to affect the public discourse in a variety of energy policy spaces. Second, we describe the types of data to be gathered from a GHP system, as well as methods and strategies for obtaining the data, where relevant. Many of the data types are not required for the analytical goals of the framework at present, but may be useful for later fundamental scientific and engineering research related to GHP technologies. Finally, we explain how various data types can be used to derive performance metrics for GHP systems. These performance metrics concern the GHP system's ability to save money for the user, reduce pollutant emissions, and favorably affect utility system peak loads.

3. UNDERSTANDING THE AUDIENCE: ENERGY DECISION-MAKING

In order for data and analysis to be useful to decision-makers, it must be relevant to their roles and responsibilities as public officials, and meet the specific challenges that they face in those roles. Different types of decision-makers approach energy policy from different positions, and with different goals in mind. A municipality, for example, may have an interest in GHP systems because of reduced end-user energy costs and greenhouse gas emissions as part of a sustainability program, while an electric utility is primarily interested in GHP systems because of their beneficial effects in reducing utility system peak loads. An impressionistic visual representation of entities engaged in energy policy, along with some of their objectives and policy approaches is shown in Figure 4. The example of the municipality versus the utility suggests a critical need to identify the various energy decision-making bodies for which GHPs may be a relevant technology, the kinds of policies that those bodies might enact, and the informational needs of the bodies in enacting a policy. Without such a roadmap of audiences, responsibilities, and procedures, any attempt to influence policy by data alone is doomed to fall on deaf ears. The data must be shaped into a compelling narrative for the right audience, or it will be ignored.

The interface between GHPs and energy policy occurs at a multitude of governance levels, including the economic regulation of electric utilities, utility responses to future emissions regulations, efficiency standards for heating and cooling technologies, planning for future interstate electricity needs, local enforcement of building codes for energy efficiency, and of course the building owner's decision to invest. Because this framework is directed toward the future construction of a database and analysis system on GHP performance that would itself be directed toward informing policy decisions, it is appropriate to discuss the agencies, mechanisms, and pathways by which policies relevant to wider GHP deployment might be made.

3.1. Federal Energy and Environment Agencies

Three federal agencies are capable of decisions that can affect GHP deployment. The Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) leads the energy efficiency research, development, and deployment efforts of the federal government, and assists the private sector in promoting energy efficient products. The Federal Energy Regulatory Commission (FERC) is an independent agency that regulates the interstate transmission of electricity and other forms of energy, and is likely to interface with GHP systems as part of its demand response initiative. The Environmental Protection Agency (EPA) protects human health and the environment through enforcement of environmental laws, and cooperates with the Department of Energy in managing the Energy Star labeling and information program. We will cover each agency separately below.

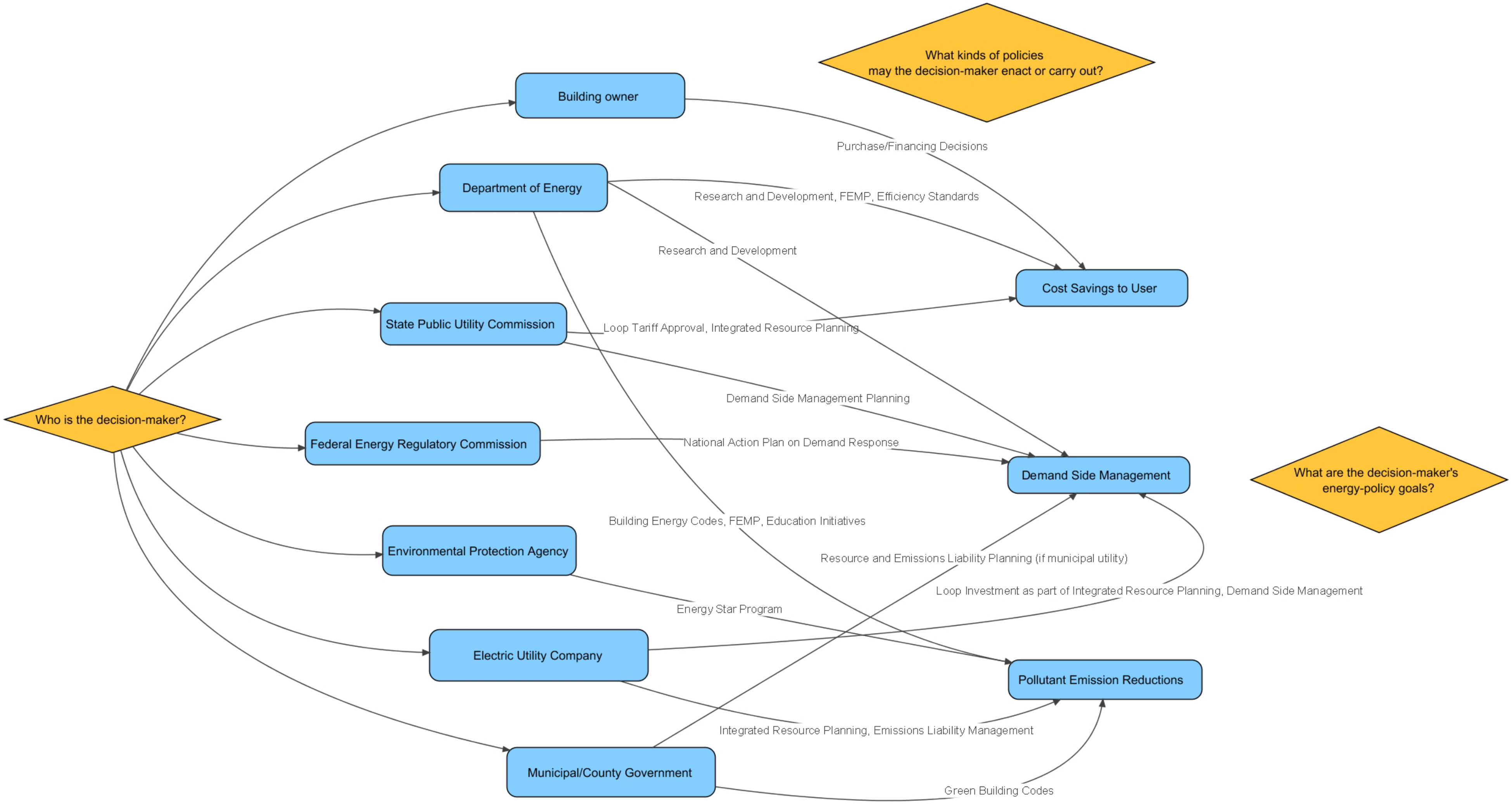

Figure 4 -- Energy Policy Decision-makers and Priorities

3.1.1. Office of Energy Efficiency and Renewable Energy (EERE)

The Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy leads the efforts of the federal government in both researching and developing new energy efficiency technologies, as well as deploying those technologies at federal facilities. In addition, EERE works with private entities and state and local governments to design policies and programs that facilitate broader deployment.[18] EERE's varied interests suggest that it will be receptive to information on facility and building level cost savings, greenhouse gas emission reductions, and peak-time energy use reductions from GHP systems.

With respect to research and development, EERE makes programmatic decisions regarding the direction of future research into energy efficiency technologies. Further research work on GHPs is needed to reduce first costs and better understand the longevity of the system as ground temperatures surrounding the loop change over the years, to name only a few concerns. Empirical data on GHP system performance can help guide DOE/EERE's decisions on research funding and objectives in the future.

Regarding energy efficiency deployment by the federal government, EERE is in charge of the Federal Energy Management Program (FEMP), which exists to ensure that federal facilities meet rigorous energy and environmental goals set by Congress. FEMP is extremely significant because the federal government oversees some 500,000 buildings nationwide, spends nearly $30 billion per year on construction, and $7 billion per year on energy costs.[19] FEMP assists federal agencies in obtaining financing for on-site energy projects,[20] assists in planning and compliance with Congressional mandates regarding renewable energy and energy efficiency deployment, and ensures that federal agencies meet requirements for inventorying and managing greenhouse gas emissions.[21] If a federal facility makes a decision to invest in heating and cooling technology, FEMP is the most likely resource it will tap for expertise on how to best meet its needs while complying with Congressional mandates. In fact, FEMP deployed a GHP program under Executive Order 13123 by President Clinton in 1999, and spent over $1 million on GHP efforts from 1998-2001.[22] Further empirical information on the performance attributes of GHP systems can provide the FEMP with the tools it needs to expand installation.

Regarding private sector deployment of energy efficiency technologies, EERE's Weatherization Assistance Program provides funding to states, U.S. territories, and

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[18] United States Department of Energy, *Energy Efficiency*, http://www.energy.gov/energyefficiency/index.htm.

[19] United States Department of Energy Office of Energy Efficiency and Renewable Energy, *Federal Energy Management Program: Sustainable Buildings and Campuses*, http://www1.eere.energy.gov/femp/program/sustainable_buildings.html.

[20] United States Department of Energy Office of Energy Efficiency and Renewable Energy, *Federal Energy Management Program: Financing Mechanisms*, http://www1.eere.energy.gov/femp/financing/mechanisms.html.

[21] United States Department of Energy Office of Energy Efficiency and Renewable Energy, *Federal Energy Management Program: Greenhouse Gases*, http://www1.eere.energy.gov/femp/program/greenhousegases.html.

[22] *See* Hughes, *supra* n 6, at 14-15.

Indian tribes, which in turn fund community action agencies, nonprofits, and local governments in providing weatherization and energy efficiency assistance to low income families. Funds are used for installation of advanced technologies to improve the energy performance of dwellings.[23] Innovative GHP systems represent one such technology that might be deployed to reduce the energy costs of low-income families, and better information about GHP systems properly communicated to EERE may result in broader use by recipients of Weatherization Assistance Program funds as well as more prominent placement in consumer education efforts by the agency.

3.1.2. Federal Energy Regulatory Commission (FERC)

The Federal Energy Regulatory Commission regulates the sale and transmission of electricity, natural gas, and oil in interstate, wholesale markets. The Energy Policy Act of 2005 empowered FERC with additional responsibilities and oversight, which it refers to as its "Top Initiatives," composed of the Smart Grid, Demand Response, and Integration of Renewables.[24] The Energy Independence and Security Act of 2007 required FERC to develop a national assessment and action plan on demand response.[25] The assessment, completed in 2009, found potential for demand reductions in peak electricity loads—those loads that occur when large spikes in demand occur, such as hot summer days, and utilities must utilize expensive and often dirty peak generation resources—of between 38 and 188 gigawatts.[26] Such actions can lower the cost of electricity and save emissions.

FERC's 2010 National Action Plan on Demand Response is aimed toward helping states maximize demand response to reduce peak loads.[27] The Plan is comprised of three approaches: technical assistance directed toward states, a national communications program for consumer education, and tools and materials for decision making on demand response strategies and technologies. Currently, the Plan's definition of demand response includes "consumer actions that can change any part of the load profile of a utility or region, not just the period of peak usage."[28] The document uses "consumer actions" primarily in the context of consumer actions taken in response to utility signals or retail rate structures that change over time, and thus the installation of energy efficiency measures such as GHPs may appear, superficially, to be outside the realm of demand response as FERC defines it.

However, significant opportunity exists to consider GHP systems as a long-term component of FERC's national demand response strategy, because of the unique

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[23] United States Department of Energy Office of Energy Efficiency and Renewable Energy, *Weatherization and Intergovernmental Program: Weatherization Assistance Program*, http://www1.eere.energy.gov/wip/wap.html.

[24] Federal Energy Regulatory Commission, *FERC: About FERC – What FERC Does*, http://www.ferc.gov/about/ferc-does.asp; FERC, *FERC: About FERC – Top Initiatives*,

[25] Federal Energy Regulatory Commission, *FERC: A National Assessment & Action Plan on Demand Response Potential*, http://www.ferc.gov/industries/electric/indus-act/demand-response/dr-potential.asp

[26] Federal Energy Regulatory Commission et al., *A National Assessment of Demand Response Potential*, June 2009, available at http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf.

[27] Federal Energy Regulatory Commission et al., *National Action Plan on Demand Response*, June 2010, available at http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf.

[28] *Id.* at 3.

characteristics of GHP systems as compared to conventional heating and air conditioning technologies. The subsurface heat source/sink for GHP systems is relatively unaffected by outdoor atmospheric temperatures, except in the uppermost 6 to 12 ft. This is important, because conventional cooling equipment, often sitting on a roof or next to a building, becomes dramatically less efficient when exposed to high temperatures, and thus contributes mightily to peak loads, even if the unit has a high efficiency rating. On the other hand, a GHP system's heat sink remains cool underground even on a hot summer afternoon, so the GHP system operates significantly closer to its efficiency rating than conventional equipment, as long as the heating and cooling load for the GHP are balanced in design.[29] The fact that a GHP system operates more efficiently during a peak period than conventional equipment means that the system can help to reduce utility system peak loads without the need for specific action on the part of the consumer.

There is no indication in the National Action Plan on Demand Response that FERC has yet considered GHP systems as relevant to demand response. Presenting credible evidence of the peak load reduction benefits of GHP systems to FERC could result in their inclusion in FERC's state technical assistance activities, and national communication program, increasing exposure for the technology.

3.1.3. Environmental Protection Agency (EPA) (Energy Star)

The Environmental Protection Agency is charged with protection of human health and the environment, and tends to regulate pollutant emissions rather than research new energy technologies. However, as the link between cleaner energy technologies and environmental quality has grown, EPA has stepped into the energy efficiency space through the ENERGY STAR program, which is jointly run by EPA and DOE. ENERGY STAR helps homes and businesses make better energy efficiency choices through tools and resources as well as an extensive labeling program from energy efficient products as well as residential and commercial buildings. Products and buildings that earn the ENERGY STAR rating must meet strict energy efficiency guidelines jointly developed by EPA and DOE.[30] Both the ENERGY STAR program and the National Building Rating Program are currently undergoing expansion and enhancement to improve impacts. Under a memorandum of understanding between EPA and DOE, EPA is the brand manager for the ENERGY STAR program, handling marketing, outreach, and monitoring and verification, while DOE performs test procedures and metrics for products and buildings.[31]

GHPs can earn the ENERGY STAR rating if they meet the required EER and coefficient of performance (COP) targets set by EPA. The targets increase over time from 2009 to 2012 as shown in Figure 5.

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[29] Personal conversation with Paul Bony, Director of Residential Market Development, ClimateMaster, August 23rd, 2010.
[30] United States Environmental Protection Agency and United States Department of Energy, *About ENERGY STAR: ENERGY STAR*, http://www.energystar.gov/index.cfm?c=about.ab_index.
[31] *Summary of EPA-DOE Partnership*, September 30, 2009, http://www.energystar.gov/ia/partners/downloads/mou/Summary_of_EPA-DOE_Partnership.pdf.

Table 1 - ENERGY STAR Requirements for GHPs (SOURCE: www.energystar.gov)

Energy Efficiency Requirements for Geothermal Heat Pumps

Table 1: Tier 1 Requirements (Effective December 1, 2009)

Product Type	EER	COP
Water-to-Air		
Closed Loop Water-to-Air	14.1	3.3
Open Loop Water-to-Air	16.2	3.6
Water-to-Water		
Closed Loop Water-to-Water	15.1	3.0
Open Loop Water-to-Water	19.1	3.4
DGX		
DGX	15.0	3.5

Table 2: Tier 2 Requirements (Effective January 1, 2011)

Product Type	EER	COP
Water-to-Air		
Closed Loop Water-to-Air	16.1	3.5
Open Loop Water-to-Air	18.2	3.8
Water-to-Water		
Closed Loop Water-to-Water	15.1	3.0
Open Loop Water-to-Water	19.1	3.4
DGX		
DGX	16.0	3.6

Table 3: Tier 3 Requirements (Effective January 1, 2012)

Product Type	EER	COP
Water-to-Air		
Closed Loop Water-to-Air	17.1	3.6
Open Loop Water-to-Air	21.1	4.1
Water-to-Water		
Closed Loop Water-to-Water	16.1	3.1
Open Loop Water-to-Water	20.1	3.5
DGX		
DGX	16.0	3.6

EPA's interest in the rated efficiency of GHP systems confirms what a policy analyst would suspect: the agency's interest lies primarily in the environmental benefits associated with reduced energy consumption by the GHP system when compared to conventional technologies. Because cost savings are a major factor in consumer purchase decisions, EPA may also be interested in cost-savings data for use on ENERGY STAR labels. EPA's efforts at driving improved efficiencies of GHP systems would likely be helped by empirical data on their actual performance.

3.2. State Public Utility Commissions (PUC) and Electric Utilities

States regulate electric utilities through both legislation and state agencies such as a Public Utilities Commission (PUC) or Public Service Commission (PSC).[32] PUCs and similar agencies exercise varying degrees of control over utility investments, rates, and future planning depending on the state legislature's grant of authority to the agency. In states with traditional regulation, service territories are prescribed for each utility operating in the state, such that each service territory has one and only one electricity provider. Other states have restructured their electricity industries so as to introduce competition in electrical generation and retail sales in service territories, while retaining a single transmission and distribution entity.

In traditional regulation states, legislatures commonly prescribe that the PUC (or its equivalent organization) inspect and approve various planning and investment decisions by major utilities, such as investor-owned utilities (IOUs). Utilities may be required to file integrated resource plans, which forecast demand and plan expansion of generation assets to meet future demand at least-cost. Integrated resource plans increasingly include environmental considerations, and as emissions become more expensive in the face of GHG emission regulation, such considerations will align with economic considerations. Legislatures may also require large utilities to implement demand side management (DSM) plans. DSM plans generally include strategies to control energy demand growth and manage peak load. In many states, DSM plans must be approved by the PUC.

In restructured electricity market states, electricity industry expansion occurs as a result of multiple electricity companies vying for customers and constructing generation assets or purchasing power from other generators according to their respective growth expectations.

Both types of regulation contemplate a variety of utility types, including for-profit IOUs, municipal utilities (owned by cities), and rural electric cooperatives (owned by electricity customers). IOUs under traditional regulation are generally subject to heavier regulation than other types of utilities because of their larger size and market share. Many municipal utilities and rural electric cooperatives purchase electricity from IOUs on long-term contracts and re-sell it to their customers. This dynamic has important implications for GHPs and energy efficiency policies.

3.2.1. The Fabled "Loop Tariff"

Ask any GHP installer in the Southwest about pro-GHP policies and you are certain to hear the words "Delta-Montrose Electric Association" (DMEA). This is because DMEA, a rural electric cooperative in the traditionally-regulated state of Colorado, has implemented a policy specifically aimed at increasing penetration of GHP systems in their service territory: a "loop tariff."[33] Despite its confusing name, a loop tariff is a

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[32] All information in this section is more comprehensively covered and dutifully referenced in Elias L. Quinn and Adam L. Reed, *Envisioning the Smart Grid: Network Architecture, Information Control, and the Public Policy Balancing Act*, 81 Colo. L. Rev. 833, 841-53 (2010).

[33] Delta Montrose Electric Association, *About Geoexchange*, http://www.dmea.com/Default.aspx?tabid=130.

simple concept. The electric utility offers to pay for, install, and own a GHP loop underneath a home or business. The home or business owner may then lease the use of the loop for a monthly rate (the “tariff”) and hook up his or her own heat pump system to the loop. Such an arrangement dramatically lowers the capital costs of a GHP system from the perspective of the home or business owner. The utility recoups the cost of the loop through the monthly tariff, and reduces its need to purchase power on the wholesale market generally, as well as its need to purchase expensive peak-time power on the wholesale market due to the efficient performance of GHP systems even during extreme temperatures. Moreover, because the utility will own the loop for decades to come – unlike a homeowner who may leave their property after 5 or 7 years – it faces much surer prospects that the loop will pay for itself through payment of the tariff by whomever is occupying the property.

The recurring question that arises regarding the DMEA loop tariff is whether the policy can be replicated elsewhere. The answer depends on a number of factors, including what type of electric utility (or utilities) is servicing the area, whether the state has a traditional or restructured electricity market, and whether political will exists in the state legislature and the PUC to pursue energy security and environmental policies with respect to electricity production.

For rural electric cooperatives such as DMEA, the decision to invest in GHP loops is procedurally simple, since cooperatives are privately owned and operated and subject to relatively little regulatory oversight. However, the decision to create a policy for such an investment at the request of a customer can be difficult. Cooperatives are often subject to long term power purchasing contracts with larger utilities that own power generation assets. Thus if a widespread installation of GHP loops results in changes in the amount of electricity needed to serve customers, the cooperative could be required to buy more power than its members will purchase back from it, or (in the case of a replacement of gas furnaces with GHP systems) may have to purchase more electricity at higher prices to meet rising demand from heat pumps. Moreover, a customer may not use the loop or pay the tariff, leaving the cooperative with a stranded asset that cannot pay for itself. Municipal utilities face many of the same challenges, but are public rather than private entities and so have greater public participation in decision-making.

For investor-owned utilities in a traditionally regulated state, implementing a GHP loop tariff or similar pro-GHP installation policy is a more complex procedural matter. This is because the electricity rates charged to customers by IOUs are carefully controlled by regulators to allow the utility a predetermined rate of return, after recouping capital and operating/fuel costs. Thus, where a widespread installation of GHP systems could reduce energy demand below what was planned for in previous years when rates were set, regulators must provide a means by which the IOU can still sell enough power to meet its capital cost needs, lest it become insolvent. This could be done by offering IOUs higher rates of return on GHP loop investments than for generation assets, as is often done for energy efficiency investments.

In a competitive market, the actors involved in the expansion of GHP systems are less certain. Some electricity companies may be interested in offering a loop tariff program to potential customers, but this would require entry by the company into an entirely new operation from generating power or the sale of electricity at the retail level. Indeed, companies having nothing to do with selling electricity could invest in loops and lease them back to customers, but it is unclear what kind of company would have the financial stability and professional background to manage such an enterprise at scale, especially in the current economic climate.

Of course, the tricky part for cooperatives, monopoly IOUs, and competitive market players alike is planning for exactly how much power is going to be added to or removed from the grid by a deployment of GHP systems. Without that knowledge, any decision-maker will be hesitant to commit capital to such a project or policy. Indeed, for traditionally-regulated states, where utilities tend to be directed to invest in energy efficiency by legislatures, and such directions are then enforced by state regulators, few legislators would be willing to press for such a specific demand as the implementation of an IOU loop tariff program without some reasonable assurance that they will not be embarrassed by the failure of GHP systems to live up to their heady economic and environmental promises.

3.2.2. Future Greenhouse Gas Emissions Regulations

Regarding audiences for GHP performance data, state electricity regulators are likely to be interested in the ability of GHP systems to lower consumer electricity bills, and are in need of information on the proper rate of return that the utility should be allowed to recoup through a loop tariff, rate rider, or inclusion of the investment in the rate base. Utilities themselves are likely to see GHP investment as an effective strategy for reducing peak loads. But both utilities and their regulators will likely become interested in the environmental benefits of GHP systems as a hedge against the possibility of carbon pricing in the future.

With the recent death on Capitol Hill of cap and trade legislation to control U.S. greenhouse gas emissions,[34] it appears a fair prediction that the role of regulating GHG emissions will fall to the Environmental Protection Agency, as mandated by the U.S. Supreme Court in *Massachusetts v. EPA*, 549 U.S. 497 (2007). This means that GHG emissions will be regulated along with other criteria pollutants such as sulfur dioxide, lead, and volatile organic compounds under the Clean Air Act. The complexities of that regulatory process are beyond the scope of this brief inquiry, but the essential upshot of such a development is that utilities will be required by environmental regulatory agencies to install control equipment to reduce GHG emissions, or to shut down generation assets that produce impermissible levels of emissions. Utilities may find it in their interest to invest in GHP loops as a means of reducing electricity loads rather than replacing old, dirty equipment with new, expensive generating assets. At scale, such actions could reduce the utility's liability for GHG emissions considerably, particularly if loops were only installed to displace electric heating and cooling.

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[34] *See* David Roberts, "On the Death of the Climate Bill," *Grist*, July 22, 2010, http://www.grist.org/article/2010-07-22-on-the-death-of-the-climate-bill/.

Regulators, likewise, will be keenly interested in the effects of such emissions regulations on electricity rates and their effects on consumers. From this perspective, a GHP system may offer both reduced emissions costs to the utility (which are in turn passed on to customers) and reduced costs to the consumer from a reduction in total demand.

In the event that a separate domestic carbon pricing scheme such as a cap-and-trade system or a carbon tax were to become law in the future, utility investment in GHP systems or loops would have a similar effect of reducing the utility's liability for emissions over its cap or tax liability. Under a cap-and-trade system, a utility would have an added incentive to reduce emissions below the cap, as it would be able to sell its excess emissions allowances to other capped entities at market prices. Utilities that could reduce emissions very cheaply in relation to other capped entities could sell excess allowances at considerable profit. Should GHP systems prove as cost effective and low-emission in the long-term as their proponents claim, utilities investing early in loop tariff policies could find themselves in a favorable position.

Finally, in the event that the U.S. becomes a party to a global GHG emission reduction treaty similar to the Kyoto Protocol (a cap-and-trade treaty that expires in 2012), the GHP industry may be capable of installing GHP systems in developing countries and selling emission reduction credits to U.S. utilities. If the transaction were properly structured, these emission reduction credits could effectively underwrite some of the cost of the GHP system.

Regardless of which path leads to the pricing of GHG emissions, utilities and state regulators have a critical need for accurate information on the performance of GHP systems with respect to cost savings, emissions savings, and peak load reduction before utilities invest in costly installations.

3.3. Local Governments and Green Building Certifiers

Increasingly, cities and counties are adopting green building codes that encourage or mandate that new structures meet environmental and energy efficiency targets in addition to the safety concerns of traditional building codes. These codes often require energy efficient lighting, superior insulation materials, careful sealing of the building envelope, and many other items or combination of items.[35] Often, a building can earn points toward compliance from each item included, until a sufficient score is reached. Cities and counties may choose to include GHP systems within green building codes as an option for reaching compliance on a new structure. The City of Boulder's Green Points program, for example, allows up to 10 points—between 16% and 100% of total points required, depending on the type and size of structure—for GHP systems.[36] A data collection and analysis system providing objective and empirical data on GHP system energy and environmental performance can provide guidance to local governments in deciding whether to provide green building compliance points for GHP systems and in what amounts.

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[35] *See, e.g.*, City of Boulder, *Green Building and Green Points Guideline Booklet*, May 2009, available at http://www.bouldercolorado.gov/files/PDS/green_points/902.pdf.

[36] *See id*. at 19.

3.4. Federal and State Revenue Agencies

The federal Internal Revenue Service allows a personal tax credit for residential energy efficiency equipment, including GHP systems, pursuant to the Energy Policy Act of 2005 and several amendments.[37] GHP owners may also claim an investment tax credit on the systems under the Renewable Energy Investment Tax Credit.[38] State revenue agencies may also provide tax incentives for GHP systems. Data demonstrating social and environmental value from GHP systems can influence such tax policy decisions.

3.5. Building Owners

Of course, all of the policy-makers discussed in this section merely create a context for the ultimate decision-maker: the building owner. While tax incentives, green building points, utility assistance, proper labeling and education, and national planning are critical to creating an environment which is conducive for GHP investment, building and homeowners must ultimately make the decision to invest. This decision is a combination of economic and social considerations, including the economic payback of the system, level of concern for the environment, and signaling of values and status to others. More accurate and objective information on the costs and benefits of GHPs with respect to economics, the environment, and the society will influence the ultimate decision to install a GHP system.

4. UNDERSTANDING THE DATA: DESCRIPTION OF DATA TYPES

4.1 Categories of GHP Data

The Geothermal Academy has developed a framework for data collection which classifies data into different categories based on the relevance of the data to understanding the energy consumption and cost of a GSHP system, as this information is the most relevant to policy and decision makers. The different types of data described in the following sections are described in detail in Appendix A.

4.1.1. Electricity and Cost Data

The first category is direct energy consumption and cost for the GHP, along with historic HVAC energy consumption and cost data, if available. The advantage of collecting this type of data is that it is the main piece of information required to assess the performance of the GHP. However, an issue with only collecting the direct energy consumption is that we may be at a loss to explain the trends in energy consumption should the system show poor efficiency. Specifically, the GHP system may be under-designed to meet the energy loads of the building, so only collecting the energy consumption may paint an unfair picture about the energy usage of GHP systems in general.

4.1.2. Performance Data

Accordingly, the second category is heat exchange performance data. This includes the measured entering/exiting water temperatures and circulation rates for the heat pump over time. The temperature data permits interpretation of the thermal energy being transferred to or from the ground. Combined with the energy consumption, this

[37] *See* 26 U.S.C. 25D.
[38] *See* 26 U.S.C. 48.

information also permits quantification of the coefficient of performance, an industry accepted metric equal to the ratio of thermal energy delivered divided by the electrical energy required to operate the system. The circulation rate indicates viscosity changes in the heat exchange fluid and may reveal leaks.

4.1.3. Design Data

A third category of data involves GHP design parameters. These include data specific to the GHP itself, including the GHP unit type, the length, dimension, and configuration (vertical or horizontal) of the heat exchangers embedded in the ground, as well as data specific to the climate setting (maximum and minimum air temperatures and relative humidity), and data specific to the building (design heating and cooling load patterns throughout the year). If the design data for a GHP system is known, then the actual performance metrics of the system may be simulated using commercially available software such as eQuest or GLHEPro.

4.1.4. Decision Data

A fourth category of data describes some of the relevant pieces of data which may affect the cost or the challenges of implementing a GHP system at a given location. The major component of this section is the up-front capital cost of the system, in terms of both the heat pump as well as the infrastructure in the ground. The cost of the heat distribution system is not included, as this is typically comparable in cost to that of a conventional heating and cooling system. This information will not help understand the performance of GHP systems, but it may provide insight into potential policy issues which may arise from the use of GHP systems. For example, the use of ground-water source heat pumps may not be suitable in some locations with extensive water-rights issues, or in locations where water removal may lead to increased salinity of the groundwater. Another example may involve the amount of space available to install vertical boreholes or trenches around a given location.

4.2. Description of the Data Collection Template

A companion document to this report is a data collection template, presented in Appendix B. This template is currently in MS Excel form, and contains tabs for each of the data categories described in the previous section. To better understand the basis of this MS Excel spreadsheet, the data for a given GHP project is implemented into the MS Excel spreadsheet in Appendix C.

This framework facilitates the collection of data based on its relevance to making policy decisions. Adoption of this framework may be facilitated by incorporating a performance collection system on each heat pump installed in the United States, capable of measuring the electrical energy consumed, the entering/exiting fluid temperatures, and circulation rates. This is a viable and cost effective solution which will provide performance data, because data collection systems are only a fraction of the cost of a GSHP unit, and because modern GSHP units already incorporate sensors to monitor energy usage and the entering and exiting fluid temperatures. Specifically, these sensors are used to control the GSHP unit to provide the heat exchange required to provide a desired temperature within a building. Accordingly, it is straightforward for this operational data to be collected to start building a database of GSHP performance such that can provide statistically relevant comparison with other heating and cooling systems. In addition to collecting the data, such a system could be easily implemented with a wireless transmitter so that data could be sent to a home PC where it could be transmitted to a central database at NREL, or monitored for personal energy evaluation.

5. UNDERSTANDING THE IMPACTS: SYSTEM PERFORMANCE METRICS

Collecting both the details of a GHP system and its time-variant data is only the beginning of a performance analysis. This section explains how to utilize the individual data points presented in Section 4 to derive meaningful analysis on the performance of GHP systems with respect to the various policy-level concerns and decision pathways explained in Section 3. It is important to note at the outset of this discussion that many of the data points from the previous section are not mentioned in this section because they are not necessary for the development of policy-level analyses. The comprehensive list of data types in Section 4 was included because its collection may provide insight into the fundamental engineering and scientific aspects of GHPs in the future. However, the aim of this report is to provide a pathway for determining the economic and emissions benefits of GHP systems rather than reveal new avenues for technological research.

The information for policy-level analyses —cost-savings, emissions reductions, and peak load impacts—is dependent on one critical piece of information: the electricity consumption of the GHP system over time. The site-specific data presented in Section 4.0 is needed to characterize the electricity consumption for a given building in a given climate and geologic setting. A GHP system's electricity consumption is the "pulse" of its performance. Combined with outside information such as the price of electricity and the emissions characteristics and load profile of the regional electricity grid, it signals how much the system costs to operate, how many emissions are attributable to the system, and how the system affects overall loads for the utility. Indeed, while a GHP system may have thousands of data points related to discrete and technical portions of the heat pump, the fluid pump, the fluid, the ground loop, and even the ground itself, the electricity consumption of the entire system is an aggregate function of all of these intertwined factors. Thankfully, producing information relevant to the policy concerns and pathways identified in Section 4 does not require determining causal relationships between technical factors and the overall electricity consumption figure.

Unfortunately, the fact that we ultimately require only one type of information from the GHP system does not make system performance analysis easy. Two vexing problems make such determinations quite challenging. First, determining the electricity consumption of a GHP system requires sub-metering of the GHP system at building level, such that one might measure the electricity consumption of the GHP system without including all other electrical loads in the structure. This capability is only available where the home or building owner has chosen to invest in special measurement technology to do so. Many home and building owners have no such technology installed, as it is not required by electric utilities which bill for the entire building's consumption. Second, and more vexing, is the determination of a baseline against which to compare the GHP system's electricity consumption. As we shall examine in the subsections below, this determination is fraught with uncertainty. Ironically, it is in the determination of this non-GHP system baseline that some of the more technical data points discussed in Section 4—specifically heating/cooling loads, building type, and building design—become relevant to performance analysis.

5.1. Baseline System Calculations

When calculating any of the performance metrics presented in this section, it is critical to determine a "baseline" against which the particular GHP system in question may be compared. This requires modeling a baseline system that would have been installed if not for the GHP system. This subsection describes the choice of a baseline system type, and the calculation of baseline system costs, emissions, and load profiles.

5.1.1. Baseline System Types

A consumer might have chosen any number of system types other than the GHP system. We present six common baseline system types here: a gas system, an electric system, a propane system, an oil system, a coal system, and an air-source heat pump system. It is important to remember that these fuel differences only apply to the heating system. The cooling system in all five system types is assumed to be electric. In some climates, cooling may not be necessary at all. In all cases, the modeling of the baseline system is dependent on the heating/cooling loads.

The size of the baseline system for residential buildings is determined by following the Manual S from the Air Conditioning Contractors of America (ACCA), while non-residential follows the Manual CS. The size of the HVAC unit is generally bigger than the heating and cooling load of the building. The fuel sources, distribution mechanism, equipment performance, local climate condition, thermostat setback recovery, supplemental heating device, and heat storage availability influence this sizing process. For example, the Manual S recommends capacity between 100 and 140% of the design heating load, while some energy experts recommend slightly higher capacity for more aggressive thermostat setback. [39]

The analysis system may take several approaches to generate an appropriate baseline. It is important to remember that the purpose of the baseline calculation is to provide a fair estimate of how much energy, emissions, and peak load contribution is truly being saved by the GHP system as compared to what the building owner would otherwise have installed. It is likely that an *ad hoc* approach, specific to each system being studied, will produce more sensible results than a plodding, mechanical analysis of all possible baseline systems for comparison. It is extremely unlikely, for example, that a commercial building owner in Denver, CO would consider using fuel oil as a heating system. On the other hand, a residential home in the Northeastern U.S. would likely consider a fuel oil system as a feasible system. Analysts using this framework must use their best discretion in choosing baseline systems that would truly be considered by the building owner. It is likely that the best way to determine what kind of system(s) to use

[39] Heating and Cooling Equipment Selection. Office of Building Technology, State and Community Programs (BTS) Technology Fact Sheet http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/26459.pdf

as the baseline is to simply ask the owner what other systems he/she was considering when making the GHP system purchase decision.

5.1.2. Modeling the Baseline System

Because the baseline system for comparison does not in fact exist, we do not have the luxury of simply measuring actual energy consumption as we do with the installed GHP system. Consequently, the analyst should use the building's characteristics and heating and cooling loads to model the performance of the baseline system or systems. Software and detailed methodologies exist to perform such modeling, but it is outside the scope of this framework to examine such tools in depth. Essentially, sufficient information must be collected on the building to model the baseline system's energy consumption over various periods of time. Annual energy consumption estimates will be sufficient for determining cost-savings, provided electricity rates are flat, and attributable pollutant emissions. But modeling the peak load contributions of the baseline system will require at least hourly energy consumption modeling, if not higher frequencies. Obviously, modeling hourly consumption is considerably more complex than modeling annual demand, and analysts must determine the feasibility of doing so on a project-by-project basis. Once sufficient modeling has produced estimates of energy consumption by the baseline system, the resulting figures could be used to produce baseline system cost estimates, emissions estimates, and in some cases peak load contribution estimates.

Cost estimates should include all expected capital, installation, operation, and maintenance costs associated with the baseline system. The costs of an HVAC unit system will be based on the list provided in the 2007 ASHRAE Handbook - Heating, Ventilating, and Air-Conditioning Applications. The estimated ownership costs include the installation cost, periodic cost, replacement cost, and the salvage value. The estimated installation costs include energy and fuel costs, heating and cooling distribution equipment costs, air treatment and distribution equipment costs, system and control automation costs, and the building's construction and alteration costs. The estimated operating costs include energy, electricity, material parts and services, and supplies costs. The energy cost is estimated from the volume of the energy source used for the system.[40] Maintenance costs are not easy to predict due to different characteristics of the system. The estimated maintenance cost may be obtained from the equipment manufacturers, contractors, and the Building Owners and Managers Association. The quantity and type of equipment, system run time, critical systems, system complexity, service environment, available infrastructure, local conditions, geographical location, and equipment age influence the maintenance costs.[41]

Baseline system emissions estimates should include estimated pollutant emissions attributable to the baseline system, even if emitted off-site, such as at the power plant generating the electricity for the baseline system. For a natural gas or propane system, pollutant emissions may be estimated directly from the estimated quantity of fuel to be used in an on-site system. For an electric system, the estimated quantity of energy used

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[40] The baseline natural gas unit may have to consider the Purchased Gas Adjustment (PGA) charges.
[41] The 2007 ASHRAE Handbook - Heating, Ventilating, and Air-Conditioning Applications

must be mapped against an emissions factor for the regional utility system. This can be done through EPA's eGRID application.[42]

Baseline system peak load contributions, if feasible, should estimate the load profile—a time-series graph of energy use over the course of a single day, such as the example shown in Figure 6—for the baseline system. Because load profiles may change dramatically according to seasonal variations, it is important to estimate load profiles for different times of year, perhaps even calculating an estimated load profile for each month of the year.

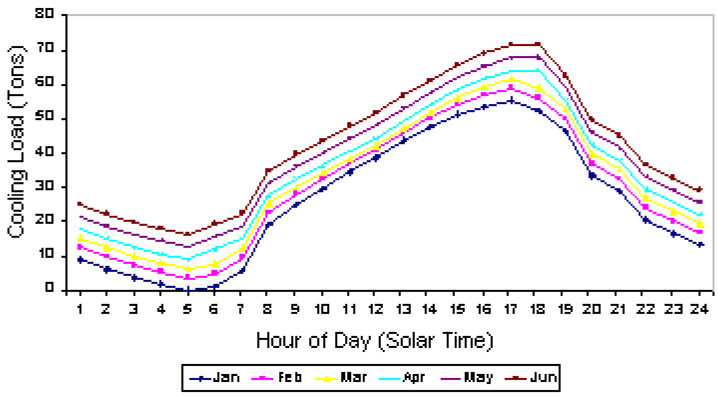

Figure 5 – An example of a typical cooling load profile measured from January to June, from <u>www.comfortair-software.com</u>

5.2. Cost Savings and System Payback Calculations

Calculation of cost savings of the GHP system involves subtracting the costs of the GHP system from the costs of a comparable baseline system over a selected period of time. As mentioned, the baseline system may change throughout the country depending on local building practices and climate. Because a GHP system may be reasonably expected to have a higher up-front cost and a lower operating cost than a conventional heating/cooling system, a longer period of time will likely allow higher cost savings to be attributed to the GHP system as the higher capital cost is "paid back" by the savings in operating costs over a period of years. Note that cost savings is measured in dollars, with the time period having been predetermined. The calculation of cost savings for the GHP system in a given year is as follows:

$$S_y = CF_{eTCy} - GHP_{aTCy} \quad (3)$$

where,

S_y = Cost Savings in Year y

CF_{eTCy} = Estimated Total Costs Incurred in Year y for Baseline System

GHP_{aTCy} = Actual Total Costs Incurred in Year y for GHP System

[42] United States Environmental Protection Agency (EPA), *eGRID*, http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. The sub-region total output emission rates in eGRID are also used in other EPA tools to calculate personal emissions and office carbon footprint, which also cover emissions from the HVAC system.

Total costs for the baseline and GHP systems may be calculated as follows:

$$CF_{eTCy} = CF_{eCCy} + CF_{eMCy} + CF_{eOCy} \quad (4)$$

where,
CF_{eCCy} = Estimated Capital Costs Incurred in Year y for Baseline System
CF_{eMCy} = Estimated Maintenance Costs Incurred in Year y for Baseline System
CF_{eOCy} = Estimated Operating Costs Incurred in Year y for Baseline System

and,

$$GHP_{aTCy} = GHP_{aCCy} + GHP_{aMCy} + GHP_{aOCy} \quad (5)$$

where,
GHP_{aCCy} = Actual Capital Costs Incurred in Year y for GHP System
GHP_{aMCy} = Actual Maintenance Costs Incurred in Year y for GHP System
GHP_{aOCy} = Actual Operating Costs Incurred in Year y for GHP System.

Cumulative cost savings for a GHP system over a baseline system may be calculated as follows:

$$S_c = \sum_{i=1}^{n} CF_{eTCi} - GHP_{aTCi} \quad (6)$$

where *i* = years 1 through n. Application of the annual and cumulative cost savings formulas above could populate a matrix dealing with different types of baseline systems, if it were likely that the building owner were considering several systems. An example matrix with a payback period of 7 years is shown in Table 2. This approach is useful because it allows comparison of payback periods between different baseline systems. Alternately, we may calculate the simple payback for a GHP system by determining the amount of time needed to reach the break-even point—the time at which the cumulative operating cost savings of the system since inception exactly equal the difference in capital costs between the GHP system and the baseline system. Unlike cost savings, which is measured in dollars with a fixed number of years, simple payback fixes the dollar amount at the break-even point, then seeks the number of years required to reach the break-even point. Calculation of simple payback for an energy efficiency investment such as a GHP system is as follows:

$$P_S = \frac{GHP_K - CF_K}{CF_{OMa} - GHP_{OMa}} \quad (7)$$

where,
P_S = Simple Payback Period
GHP_K = Capital Cost of GHP System
CF_K = Capital Cost of Baseline System
CF_{OMy} = Average Annual Operating and Maintenance Costs of Baseline System
GHP_{OMy} = Average Annual Operating and Maintenance Costs of GHP System.

Table 2: Annual Cost Savings Calculation Matrix

Year	GHP system costs	Gas system costs	Electric system costs	Propane system costs	Savings over Gas system	Savings over Electric system	Savings over Propane System
1	GHP_{aTC1}	GCF_{eTC1}	ECF_{eTC1}	PCF_{eTC1}	GCF_{eTC1} GHP_{aTC1}	ECF_{eTC1} GHP_{aTC1}	PCF_{eTC1} GHP_{aTC1}
2	GHP_{aTC2}	GCF_{eTC2}	ECF_{eTC2}	PCF_{eTC2}	GCF_{eTC2} GHP_{aTC2}	ECF_{eTC2} GHP_{aTC2}	PCF_{eTC2} GHP_{aTC2}
3	GHP_{aTC3}	GCF_{eTC3}	ECF_{eTC3}	PCF_{eTC3}	GCF_{eTC3} GHP_{aTC3}	ECF_{eTC3} GHP_{aTC3}	PCF_{eTC3} GHP_{aTC3}
4	GHP_{aTC4}	GCF_{eTC4}	ECF_{eTC4}	PCF_{eTC4}	GCF_{eTC4} GHP_{aTC4}	ECF_{eTC4} GHP_{aTC4}	PCF_{eTC4} GHP_{aTC4}
5	GHP_{aTC5}	GCF_{eTC5}	ECF_{eTC5}	PCF_{eTC5}	GCF_{eTC5} GHP_{aTC5}	ECF_{eTC5} GHP_{aTC5}	PCF_{eTC5} GHP_{aTC5}
6	GHP_{aTC6}	GCF_{eTC6}	ECF_{eTC6}	PCF_{eTC6}	GCF_{eTC6} GHP_{aTC6}	ECF_{eTC6} GHP_{aTC6}	PCF_{eTC6} GHP_{aTC6}
7	GHP_{aTC7}	GCF_{eTC7}	ECF_{eTC7}	PCF_{eTC7}	GCF_{eTC7} GHP_{aTC7}	ECF_{eTC7} GHP_{aTC7}	PCF_{eTC7} GHP_{aTC7}
Cumulative	GHP_{aTCc}	GCF_{eTCc}	ECF_{eTCc}	PCF_{eTCc}	GCF_{eTCc} GHP_{aTCc}	ECF_{eTCc} GHP_{aTCc}	PCF_{eTCc} GHP_{aTCc}

5.2.1 System Capital Costs

Capital cost, as used in this document, refers to all costs incurred in the initial installation of a GHP system. Note that this includes the cost of labor for installation as well. This figure may also be referred to as the "first cost" or "up-front cost" of a GHP system. Calculating capital costs requires a summation of the following costs (where applicable):

- Initial testing and system design
- Drilling/trenching
- Loop and loop installation
- Heat pump and heat pump installation

Capital costs may vary according to a number of factors listed in Section 4 of this document, *supra*. Table 3 lists such relationships in a non-exhaustive format, for impressionistic purposes.

Table 3: Some Relevant Data that Influences Capital Cost Factors

Data Type	**Influences on Capital Cost Factors**
Thermogeology and Hydrogeology Data	Loop and loop installation, Heat pump
Geology Data	Initial testing, drilling/trenching, loop installation
Surface Land Availability	System design, drilling/trenching, loop installation, heat pump
Groundwater Availability	System design, loop, heat pump
Local Climate Conditions	System design, loop, heat pump
Geographical information	System design, loop, heat pump
Loop System, length and Configuration	Loop, drilling/trenching, heat pump
Total Borehole Depth and Number of Boreholes	Drilling
Trench size	Trenching
Heating/Cooling Loads	Heat pump, loop, drilling/trenching

As data from actual systems is gathered in a future data collection system, opportunities exist to examine these relationships quantitatively and empirically. For example, an analyst might track the influence of soil geology on drilling and loop installation costs over a large number of installed systems, and contribute to a better understanding of the main determinants of capital costs for GHP systems. Such understanding could lead to better forecasting of system costs or drive research toward better methods for dealing with certain types of soils.

5.2.2. System Maintenance Costs

System maintenance costs include all costs incurred after initial installation of the system, but unrelated to the cost of operating the GHP system on a daily basis. Effectively, maintenance costs function as a "catch-all" basket for any costs not included in capital or operating costs.

In some cases, maintenance costs will be very low, possibly related only to servicing of components in the heat pump unit from time to time. However, other cases might demonstrate very high maintenance costs, as might occur where a system was improperly designed or installed, and must be excavated, repaired, or augmented at a later date.

5.2.3. System Operating Costs / Annual Energy Throughput

System operating costs refer to the cost of electricity needed to run the GHP system. Where electricity costs per kilowatt-hour ($/kWh) to the consumer are constant, this cost may be calculated by multiplying the quantity of electricity consumed by the flat electricity rate. Thus,

$$GHP_{aOCy} = Q_e * r \qquad (8)$$

where,
GHP_{aOCy} = Actual Operating Costs Incurred in Year y by GHP System
Q_e = Quantity of Electricity Consumed by Heat Pump in Year y (in kWh)
r = rate of electricity for consumer (in $/kWh).

Not all electricity rates are flat. Some electric utilities use inclining block rates, which vary the price of electricity each month according to the customer's cumulative consumption of electricity for that month. A consumer under an inclining block rate scheme will thus pay a low rate for the first "block" of electricity consumed during the month. Once a threshold level of consumption for the month is reached, the rate rises. Other electric utilities use variable or dynamic rates, where the price of electricity changes throughout the day according to pre-set schedules or exactly tracks the utility's marginal costs of electricity production, respectively. In both cases, calculating operating costs requires multiplying the quantity of electricity consumed at a particular rate by the rate itself, and then summing all products:

$$GHP_{aOCy} = \sum_{i=1}^{n} Q_{ei} * r_i \qquad (9)$$

where,
i = rates 1 through n
Q_{ei} = quantity of electricity consumed at rate *i*.

Measuring consumption at specific times of day that coincide with specific rates will require advanced metering technology (AKA, "smart meters"), which ought to have been deployed wherever dynamic or time-of-use rates are in effect because they are needed for the utility's billing purposes. Depending on the information-control regulatory scheme in place, electricity usage data may need to be procured from utilities or directly from consumers.[43]

When comparing GHP operating costs to estimated baseline operating costs under variable rate schemes, it is important to model the time of energy usage by the baseline system independently of the GHP system's actual usage, because GHP systems may not exhibit the same load profiles or quantities as other systems.[44] Section 5.1.2 discusses modeling of baseline system load profiles based on a building's heating and cooling loads.

[43] *See* Elias L. Quinn and Adam L. Reed, *Envisioning the Smart Grid: Network Architecture, Information Control, and the Public Policy Balancing Act*, 81 Colo. L. Rev. 833, 861-81 (2010).
[44] Personal conversation with Paul Bony, Director of Residential Market Development, Climatemaster, August 23rd, 2010.

An additional data collection problem arises in the need to differentiate the load for the GHP system from the cumulative load of the entire structure. In the case of a smart-grid-connected building, equipment may already be in place to measure and control the heat pump in accordance with utility peak load reduction applications. But without appliance-specific monitoring and control technology, data collection parties will need to either install electricity consumption monitoring equipment or estimate GHP system electricity consumption as a function of total consumption based on reasonable assumptions.

5.3. Emissions Reductions

Emission reductions from the GHP system may be calculated as follows:

$$ER_y = CF_{eEy} - GHP_{aEy} \quad (10)$$

where,
ER_y = Emissions Reductions Attributable to GHP System in year y
CF_{eEy} = Estimated Emissions of Baseline System in year y.
GHP_{aEy} = Actual Emissions of GHP system in year y.

The CF_{eEy} calculations were explained in section 5.2. Like the CF_{eEy} calculation, GHP_{aEy} may be calculated using EPA's eGRID application. The Emissions & Generation Resource Integrated Database (eGRID)[45] provides data on air emissions of nearly all electric power generated in the U.S. Users of eGRID can examine emissions data on a power plant, utility, state, or regional basis, among others. Such emissions data can be utilized for calculating GHP emissions information as follows:

$$GHP_{aEy} = (Grid_E \times GHP_{aEly}) \quad (11)$$

where,
$Grid_E$ = Total output emission rates data from eGRID (in lb/MWh for CO_2 and lb/GWh for N_2O and CH_4)
GHP_{aEly} = Electricity consumption of the GHP system in year y (in MWh for CO_2 and GWh for N_2O and CH_4)

In the case that the GHP system is not the only HVAC system for the building, additional emissions from the complementary system will need to be included in the calculation. Future efforts at calculating environmental performance could include measurement of more forms of primary energy used in the production of electricity, *e.g.*, drilling, mining, transportation, water management, etc. These aspects are too complex to tackle in this document, but may be included in later iterations of the framework beyond the completion of this project.

5.4 Peak Load Impacts

The potential benefits of a GHP system are not limited to the owner or operator of the system itself. A GHP system may also provide cost and emissions savings to the electric utility through its effects on utility system peak load. "Peak load" refers to brief periods of the day where an electric utility must meet exceptionally high demand for electricity, such as a hot summer

[45] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

afternoon. In order to meet peak loads, utilities must use expensive and rarely-operated peaking resources – such as diesel generators – that can ramp up power production to meet peak load very rapidly. Power produced from peaking resources is more expensive than power produced from base load (generally coal) or shoulder load (generally natural gas) resources, and often has higher emissions per kWh than other generation resources. It is thus in the interest of utilities to seek strategies for minimizing peak loads and reducing reliance on peaking resources.

GHP systems may provide peak reduction services in two ways. First, a GHP system's lower total energy consumption reduces overall demand, including peak demand. Second, GHP systems may exhibit different daily load profiles from conventional electric systems, which may provide further peak demand reduction.[46] Where the load profile of a GHP system differs from the load profile of the electric utility such that GHP system electricity demand is non-coincident with utility system peaks, these further reductions are realized. This effect would be most noticeable where the GHP system is very large or where a large number of smaller GHP systems have been installed, and thus a significant portion of heating and cooling in an area now exhibits GHP-type load profiles.

Determining the peak load impacts of a GHP system requires knowing the hourly load profile of the GHP system, the estimated hourly load profile of a baseline system, and the hourly load profile of the electric utility.

The hourly load profile of the GHP system may be constructed from energy usage data gathered through consumer-side smart grid components (where installed) such as smart plugs. Where a site does not have such devices, separate monitoring equipment will be required. Such monitoring equipment could be installed by the building owner/operator, or by the GHP system installer as part of a performance monitoring plan.

The estimated hourly load profile of a baseline system may be constructed as explained in Section 5.1.2.

Detailed utility system daily load profiles may be acquired through data provided to the Federal Energy Regulatory Commission (FERC) in FERC Form No. 714, Part III – Schedule 2. Planning Area Hourly Demand. FERC provides a viewer for such data, which can be downloaded at http://www.ferc.gov/docs-filing/forms/form-714/view-soft.asp.

It is important to understand that system load profile alone will not provide information on what mix of resources is being used to generate the electricity. Thus the system load profile will only provide general information on aggregate demand for a given utility. As a first-stab at determining peak load impacts of GHP systems, this data would allow calculation of average daily load profiles for the utility in question for each month of the year. This allows comparison of a representative utility load profile for a given month against the load profile of the GHP

[46] It is important to note here that peak load reduction benefits of GHP systems with respect to utilities presume that the baseline system is electrically-based. Where the baseline system would use no electricity – e.g., a propane heating system in a climate that has little to need for cooling applications – a GHP system would likely provide no peak load reduction benefits, and may actually increase electricity loads.

system and baseline system. This comparison would be capable of answering the following questions:

1. Whether the GHP system's loads are non-coincident with utility system peak demand; and
2. How much utility peak demand reduction the GHP system provides compared to the baseline system's expected demand.

A later iteration of the analysis system proposed in this document might attempt to model the resource mix for the utility at given times of the load profile. This would require data regarding the utility's generation asset mix, fuel mix, and marginal costs ("system lambda," also available through the FERC Form 714 viewer). An analyst would then need to perform a constrained optimization study based on the technical capabilities of the utility system, the economics of generation for various resources, and total demand. Such detailed information would allow for estimation of both savings in utility operational costs and utility capital costs due to the GHP system's more favorable load profiles. Of course, performing this kind of detailed analysis is time-consuming and expensive, and would not be feasible for every system examined under a nationwide GHP data collection effort.

5.5. Social and Behavioral Factors

In addition to economic and technical information, a comprehensive framework for determining the performance of GHP systems should include human factors as well, such as inhabitant comfort and other attitudes toward the technology by users. Methodologies for measuring such factors through questionnaires are explained below, and are quite straightforward.

However, procuring social and behavioral data from building users after some time has elapsed between the installation of the GHP system and the mailing of the questionnaire may be difficult. Such strategies tend to have low response rates. Response rates might be improved by tying completion of questionnaires (and perhaps provision of data for economic and technical analysis as well) to rebates or other financial incentives. An informational campaign aimed at system owners and backed by the Department of Energy could also improve participation.

5.5.1. Inhabitant Comfort

Inhabitant comfort refers to the satisfaction of building occupants with the space conditioning services provided by the GHP system. A system that saves money and emissions but fails to keep inhabitants comfortable will never see widespread adoption. Anecdotally, GHP systems are thought to provide high levels of satisfaction to owners, providing comfortable temperatures, low sound volume, and few outages. Information on satisfaction can be gathered through the use of a simple scale on an inhabitant questionnaire, such as this example questionnaire:

- How satisfied are you with the heating performance (if applicable) of your GHP system?
    1 Completely Dissatisfied
    2 More Dissatisfied than Satisfied
    3 Indifferent
    4 More Satisfied than Dissatisfied
    5 Very Satisfied
- How satisfied are you with the cooling performance (if applicable) of your GHP system?

1 Completely Dissatisfied
2 More Dissatisfied than Satisfied
3 Indifferent
4 More Satisfied than Dissatisfied
5 Very Satisfied

- How satisfied are you with the noise level of your GHP system?
  1 Completely Dissatisfied
  2 More Dissatisfied than Satisfied
  3 Indifferent
  4 More Satisfied than Dissatisfied
  5 Very Satisfied
- How satisfied are you with the reliability of your GHP system?
  1 Completely Dissatisfied
  2 More Dissatisfied than Satisfied
  3 Indifferent
  4 More Satisfied than Dissatisfied
  5 Very Satisfied
- Would you recommend a GHP system to other people?
  (yes/no/explain why)
- Do you use a back-up system with your heat pump?
  (yes/no)
- How often do you use the back-up system?
  (weekly / monthly / a few times per year / not at all)
- In what conditions do you use the back-up system?
  (hot weather / cold weather / moderate weather)
- How frequently have you had to have the GHP system serviced? (monthly / weekly /seasonally / annually / every _ years) If so, which components of the system are typically serviced?

5.5.2. Inhabitant Attitudes toward Energy Consumption and Climate Change

In what is becoming a well-known phenomenon, purchasers and users of energy efficiency products – particularly those providing feedback to consumers on energy use – tend to become more aware of other energy efficiency products and strategies, and begin adjusting their preferences and behaviors in an upward spiral of energy efficiency. Researchers have coined this phenomenon "the Prius effect" after the Toyota hybrid vehicle that provides drivers with immediate information about gas and electricity consumption while driving. Prius drivers were more likely to accelerate and brake gently to conserve fuel than drivers of other vehicles. Moreover, ownership of the Prius tends to affect the consumer's construction of self-identity, such that buying green products and engaging in energy efficiency behaviors becomes a matter of personal expression.

The ability of GHP systems to spark related energy efficiency behaviors is unknown and uncertain, largely because of the invisibility of a system once it is installed. Unlike solar panels or hybrid cars, GHP systems do not generally present themselves to the naked eye. However, the dramatic potential effect of GHP systems on customer energy usage and utility bills may be a mechanism for leveraging the system to increase consumer awareness of energy consumption, and thus drive greener energy choices.

Tracking this kind of effect with specificity is certainly challenging, and would require collection of data on building and home owners regarding energy efficiency and renewable energy investments made well after installation of the GHP system. A more manageable, but less accurate, approach might examine intent to make such purchases. Such an approach could include the following question in the questionnaire suggested in Subsection 5.5.1.:

- Have you invested or do you plan to invest in any of the following other energy efficiency or renewable energy investments in the foreseeable future? (check all that apply)
  - Solar Photovoltaic System
  - Solar Hot Water
  - Insulation and Sealing
  - Smart Home Devices for Appliance Control
  - Geothermal Heat Pump (for another structure)
  - High-efficiency boiler/chiller
  - High-efficiency lighting
  - Wind power system
  - Green power purchasing from local utility
  - Hybrid electric or plug-in electric vehicle
  - Bio-ethanol or Bio-diesel powered vehicle
  - Other (specify) _______________
- What was your number one factor for installing a heat pump? cost? environment, comfort?
- Who is the decision-maker in the household regarding energy efficiency and home investments?
- How big a problem is climate change?
- How long do you plan on staying in the house?
- How old is your house?
- If commercial building, how do you expect this system to affect rental rates?

6. TESTING

The framework discussed in Section 4.2 was implemented and refined for several real projects with GHP installations throughout Colorado. These installations include:

- Kinard Middle School, Poudre Valley School District, Ft. Collins, Colorado
  - Ground-Source Heat Pump System
  - 73 GHP heat pumps
  - One hundred 200 ft-deep wells
- Governor’s Mansion, Denver, Colorado
  - Groundwater Heat Pump System
- Senior Living Facility, Denver Housing Authority, Denver, Colorado
  - Ground-Source Heat Pump System
  - Forty 470 ft-deep wells

Although design-level data was available at all of the sites, electrical consumption data specific to different GHP systems nor their performance data was available for these projects. This prevented the metrics from being evaluated for real GHP systems. Nonetheless, the lack of the most relevant data permitted the refinement of the framework by prioritizing the collection of different types of data, to emphasize that data on electrical consumption and performance, collected after installation of the GHP systems is critical. An example of the data framework implementation for the Kinard project is also included in Appendix D of this report.

7. CONCLUSION AND RECOMMENDATIONS

This document presents a framework for data collection and analysis pertaining to installed geothermal heat pump systems in residential and commercial buildings. It is important to remember that this is not a framework for determining complex causal relationships between site-specific attributes and GHP performance, but rather a framework for fairly assessing the economic, environmental, and societal benefits of GHP systems and presenting such assessments to policy-makers within the proper context for action, if warranted.

Because the data collection efforts in this study ended up leading to refinements of the data collection framework, but not to an implementation of the metrics, efforts should be made to collect data from future installations or retrofits. Accordingly, the main recommendation of this report is to include a minimal data collection system on each heat pump installed in the United States, capable of measuring the electrical energy consumed, the entering/exiting fluid temperatures, and circulation rates. This is a viable and cost effective solution which will provide performance data because data collection systems are only a fraction of the cost of a GHP unit, and because modern GHP units already incorporate sensors to monitor energy usage and the entering and exiting fluid temperatures. Specifically, these sensors are used to control the GHP unit to provide the heat exchange required to provide a desired temperature within a building. Accordingly, it is straightforward for this operational data to be collected to start building a database of GHP performance such that can provide statistically relevant comparison with other heating and cooling systems. In addition to collecting the data, such a system could be easily implemented with a wireless transmitter so that data could be sent to a home PC where it could be transmitted to a central database at NREL. Display of the data on a user's PC would provide feedback on the performance of their system which could perhaps refine their use of the system to reach their personal energy goals.

Although a system has yet to be incorporated directly into commercial GHP systems, it is straightforward and inexpensive to outfit a GHP with a data acquisition system and supplemental sensors. A secondary recommendation is to consider funding a pilot effort that will collect the energy and performance time series data from a representative sample of installations. A pilot effort could be implemented rather easily, building upon the relationships developed as part of the formation of the Geothermal Academy. It would be most suited to evaluate the performance of GHP installations in different climate settings, preferably focusing on residential, commercial, and public buildings. If such a pilot effort were to be undertaken, it is recommended to also identify large buildings which may incorporate a back-up conventional heating and cooling system, and also incorporate monitoring systems. This would provide statistically relevant comparison data to assess the improvement in GHP energy usage over other heating and cooling technologies.

Such a data collection system would provide several benefits to the different sectors of society which are concerned with GHP technology and implementation. A summary of the benefits for each sector are summarized below:

Consumers

- Routine free "health" diagnostics
- Prevention of an expensive damage/repair
- Contributing towards saving energy and reducing GHG emission; the "makes me feel good" effect
- Reduce monthly electricity bill

Installers

- Rapid increase of sales due to gained confidence of consumers
- Long-term customer care service to strengthen a trusting relationship
- Provide a comprehensive history of an installed unit, providing better diagnostics and repair strategies
- Elimination of unqualified installers

Policy Makers

- Statistically relevant data which could be used to justify policy decisions.
- Information on the benefits of tax credits and other implementation strategies.

Geothermal Academy and GHP Researchers

- Archived time series data can be used to validate the theory behind simulation and design tools
- Database of thermal conductivity and cost data for different locations and geologic settings can be used to facilitate the design process
- Provide further opportunities for research on climate change issues in collaboration with the National Geothermal Data Systems
- Opportunity to develop iPhone and other smart phone applications to promote consumer awareness [jointly with NREL and other interested parties]
- Can study an exciting area of economics called "the virtual economy"
- Opportunity to study how the consumer behaves when a new technology is introduced
- Research how the collected data can be used to influence policy makers

Utility Companies and Government Regulators

- Real-time monitoring will provide utility companies with feedback on the peak load —there is a growing concern about the fact that our aging grids may not be able to handle electricity sent in by solar power at peak time
- Minimizing GHG consumption

APPENDIX A: EXPLANATION OF GHP DATA TYPES

This appendix includes a comprehensive overview of the various types of data that may be collected from GHP systems to evaluate their performance and cost. The order of presentation of the data in this appendix follows the priority for collecting the data. It is expected that on a typical GHP product much of this information will not be available. It should also be noted that the GHP energy consumption data and performance data are functions of time. In other words, this data should ideally be collected after installation for several years in order to quantify the long-term performance of GHPs. A blank series of worksheets which can be used to organize the data types for a GHP project is presented in Appendix B, while a completed series of worksheets with typical plots is shown in Appendix C.

A1. GHP Energy Consumption Data

A1.1. Electricity Consumption

Information about the actual power consumption for a GHP system will permit direct quantification of the efficiency of GHP systems compared to conventional energy savings and emission reductions. This information can be obtained from an electricity meter connected to the heat pump itself, or it can be obtained from the heat pump operating system. Many heat pumps contain computers and display panels which note temporal changes in electricity consumption.

A1.2. Operating Cost

The operating cost for a GHP can be obtained directly by multiplying the electricity consumption of the GHP system by the cost per kWh from an electricity provider. It is also possible to glean the contribution of a heat pump from the household electricity bill, but this may be complicated in a busy household with other sources of electricity demand.

A1.3. Maintenance Cost

Maintenance costs are an important part of evaluating the long-term costs of a heating and cooling system. Any heating and cooling system requires periodic maintenance to ensure proper operation. The database for GHP maintenance has not been widely developed yet, so additional information on this topic would permit better evaluation of the long-term comparison between GHPs and conventional heating and cooling systems. The maintenance costs expected from GHPs are flushing of air bubbles from the ground loop system, replenishing antifreeze or refrigerant, and cleaning the air handler within the building.

A2. GHP Performance Data

A2.1. Entering and Exiting Ground Loop Temperatures

The entering and exiting temperatures for the ground loop (the temperature of the heat exchanger fluid in the ground loop when it leaves the heat pump and enters the ground, and the temperature of the heat exchanger fluid when it returns to the heat pump after circulating in the ground, respectively) directly reflect the heat exchange from the ground to the building. These temperatures can be monitored using thermocouples inserted into the heat exchange tubing when it leaves and enters the heat pump. Most modern heat pump systems also monitor the entering and exiting ground loop temperatures because this data is used to control the heat pump operation. Some heat pumps can be configured to collect this information over time, or to display this information on the control screen.

A2.2. Circulating Pump Performance

The flow rate of the heat exchanger fluid (in gallons per minute) in the ground loop is an important variable as it can reflect leaks in the ground loop, changes in viscosity of the heat exchange fluid, and whether or not turbulent flow is occurring. The flow rate should be great enough to ensure turbulent flow conditions in the heat exchanger pipe.[47] This permits heat transfer between the fluid and the heat exchanger piping by convection rather than by conduction. The pump performance can be inferred directly by collecting the electricity consumption of the circulation pump. It can also be inferred using a differential pressure transducer in the ground loop before and after the circulating pump.

A3. GHP Design Data

If the performance data is not available for a project, the performance of a GHP system can be simulated using commercially-available design software. This approach incorporates uncertainty from several aspects, because the design must incorporate characteristics of the geologic setting, the building, and the ground loop. Although it is preferable to have performance data over design data when making policy-level decisions about GHP performance, design data may be used to interpret why or why not a GHP system is functioning as intended.

A3.1. Geologic Setting Data

The geologic setting at the location of a GHP installation has an important influence on the design of a GHP system because the characteristics of the soil or rock at a particular location, along with their thermo-geological properties reflect the ease of transferring heat to and from the ground by the GHP system. It is important to note that groundwater **does not** need to be present for the design of a closed ground loop, although groundwater can lead to an increase in thermal conductivity by a factor of 10.

A3.1.1. Temperature Profile and Geothermal Gradient

There are three critical factors necessary for the design of residential and commercial closed ground loop heat exchangers:

1. Undisturbed ground temperature, typically expressed on °F
2. Average thermal conductivity, expressed in BTUh/ft/°F
3. Diffusivity, expressed in ft^2/day

Undisturbed ground temperature is required for either residential or commercial closed loop ground heat exchangers. Many closed loop ground heat exchangers, both vertical and horizontal systems, are installed in geologic conditions with little or no ground water.

For closed loops in surface water applications – pond or lake loops – the seasonal minimum and maximum water temperatures should be understood for competent ground loop design requirements.

The temperature difference between the ground and the building is critical to the design of the system. It indicates the amount of heat that can be transferred from/to the ground to the building. The ground temperature (in °F or °C) below a certain depth depends on the annual average air

[47] Banks, 2008.

and soil temperature and the upward geothermal gradient. The geothermal gradient varies with the geologic and techtonic setting. Locations with a high geothermal gradient typically have hot springs at the ground surface. Geophysical logging or published databases from USGS or local geological survey can be used to provide ground temperature and geothermal gradient data.

A3.1.2. Groundwater Temperature

For open loop systems, such as those using water from a water well, the average annual water temperature must be accounted for. Well log reports published by the local water board are typically a good location to obtain water temperature information. Locations with groundwater flow are particularly suited for open loop GHP systems because the flowing groundwater replenishes heat extracted or dumped into the ground.

A3.1.3. Frost Depth

Horizontal and vertical closed ground loops are typically designed so that they lie below the depth of frost penetration. This is more important for horizontal trenched or pit ground heat exchangers. Horizontal loops must also account for annual temperature swings; deeper horizontal loops are less subject to these impacts. Vertical loops are usually not subject to climate impacts, but must be headered or tied into the supply/return piping back to the HP system at a reasonable depth to minimize climate or other surface impacts. Information on frost depth can be found in most foundation design texts.

A3.2. Geomaterial Data

A3.2.1. Classification and Mineralogy

Geology and hydrogeology data influence the GHP system design through the thermal properties of the soil, and can also impact the construction work requirements to install the system. Further, lithographic information is useful for predicting the required construction works in installing and designing a GHP system. This information includes rock types, hardness, porosity, water content, and mineralogy. The rock type determines the construction work needed to install the ground loop, a major component of total installation cost. The thermal conductivity and specific heat capacity of geomaterials are directly related to the mineralogy, porosity, and gravimetric water content of the geomaterial. Geologic mapping and sampling through trenching or drilling can be used to obtain soil and rock classification data.

A3.2.2. Thermal Conductivity

Thermal conductivity of a geomaterial (soil and rock) represents its ability to conduct heat under application of a temperature gradient. Conduction is an important heat transfer process in which heat flows through a geomaterial by molecular interaction. In GHP systems, heat transfer by conduction occurs in several different situations. First, heat flows from the heat exchanger embedded in the borehole into the surrounding rock or soil by conduction. This is directly related to the rate at which heat can be extracted or injected into the subsurface by the heat exchanger. Second, heat flows from the atmosphere into the subsurface due to the daily and seasonal fluctuations in air temperature and solar radiation boundary conditions at the ground surface. Third, heat can flow from the interior of the building can be transferred via conduction through the floor slab of the building into the subsurface. For soils, the magnitude of thermal conductivity is dependent on the soil's degree of saturation, mineralogy, porosity, density, and pore water mineral properties. The degree of saturation can lead to a change in thermal conductivity by approximately an order of magnitude, with a dry soil having a lower thermal conductivity. Nonetheless, soils with high quartz content can still have a high thermal conductivity when dry because quartz has a thermal conductivity which is approximately 10 times greater than water. The units for thermal conductivity are $W \cdot K^{-1} \cdot m^{-1}$. Laboratory or in-situ tests can be used to obtain the soil-specific magnitude of thermal conductivity. The thermal conductivity test used for soil specimens in the laboratory is the thermal needle test, while the thermal conductivity test used in GHP application is the borehole thermal conductivity test.[48] Both tests use the line-source heat conduction equation to solve for the thermal conductivity.

A3.2.3. Specific Heat Capacity

The specific heat capacity is a parameter which indicates the ability of a geomaterial to store heat while undergoing a temperature change (but without undergoing a phase change). This value is equal to the heat energy required to change the temperature of the geomaterial by 1 °C. This is related to the volumetric heat capacity, which is normalized by the volume of the material instead of by the mass. The specific heat capacity does not depend on the amount of geomaterial present, while the volumetric heat capacity does.

A3.2.4. Hydraulic Conductivity

The hydraulic conductivity (LT^{-1}) of soil indicates the ease by which water moves through the pore space under the application of a hydraulic gradient. Similarly, the hydraulic conductivity of rock indicates the ease of water movement through either the rock matrix or through a discrete fracture. This variable is important for estimating the flow rate of ground water in an open loop system of a groundwater heat pump (GWHP) system. A GWHP system extracts groundwater in an aquifer to transfer heat from/to the ground to/from a building. The hydraulic conductivity is dependent on the porosity, grain size, mineralogy, and the degree of cementation. Well pumping tests can provide hydraulic conductivity data of aquifers used in open-loop systems.

A3.3. Building Heating and Cooling System Data

A3.3.1. Local Climate Conditions

Local climate data is an important component to assessing the performance of a GHP system. Climatic data should be collected on a daily basis, and should include the maximum, minimium, and average values of the air temperature, relative humidity, wind speed, and barometric pressure. The wind direction, ground temperature, and precipitation are also important variables in soil-atmosphere interaction modeling. The 2005 ASHRAE- handbook fundamentals provides local climate conditions for 5664 stations in the United States, Canada, and around the world. The climate data are based on long-term hourly observations (1982-2006 for most locations in the United States and Canada). Data at each location include the latitude, longitude, elevation, standard pressure at elevation, time zone, and period of analysis. This information can also be obtained from online databases which archive data obtained by NOAA, such as the weather underground site (http://www.wunderground.com).

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[48] *See* T.L. Brandon and J. K. Mitchell, *Factors Influencing Thermal Resistivity of Sands*, Journal of Geotechnical Engineering, Vol. 115, No. 12, December 1989, pp. 1683-1698, (1989) for the needle test and see John A. Shonder and James V. Beck, Field Test of a New Method for Determining Soil Formation Thermal Conductivity and Borehole Resistance, *ASHRAE Trans*., vol. 106, part 1, pp. 843–850, (2000) for the borehole thermal conductivity test.

A3.3.2. Geographical Information

Whether a building is in a rural or urban environment can provide important information on the space availability. Geographical information variables are associated with the heat gain from solar radiation, which is important for the heating and cooling load calculation. They include latitude, longitude, time zone, and elevation. This information helps to estimate local climate conditions.

A3.3.3. Building Type and Design

The building type (residential and non-residential) influences the heating/cooling load for the GHP system. These two types of building have different design and usage characteristics. The design parameters that determine the heating/cooling load are: number of occupants, lighting configuration, types of appliances, electric motors in the building, wall, window, ventilation, roof and floor, insulation, exposed surface area, the temperature of unconditioned space.

A3.3.4. Indoor Design Conditions

Indoor design conditions consist of the expected indoor temperature and relative humidity, and are based on inhabitant comfort. The typical residential heating practice aims at 68^{o}F and 30% relative humidity while the cooling practice aims at 75^{o}F and 50 to 65% relative humidity. This information is useful for calculating the heating/cooling load of the building.

A3.3.5. Heating/Cooling Loads

The building heating/cooling load is the rate of heat required to be moved to maintain the desired level of temperature inside the building (BTU/h). The local climate, geographical condition, building type and design and the indoor design condition are the main categories of information required to determine the heating and cooling load.

The 2009 ASHRAE Handbook Fundamentals from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provides information about the Heat Balance and Residential Load Factor methods to calculate the heating/cooling load. The heat balance method assumes that heat transfer processes occur simultaneously and continuously.[49] This method involves an iterative process to calculate the cooling load (q_{sys}) based on four distinct processes: outside face heat balance, wall conduction, internal heat balance, and air heat balance (illustrated in Figure 1). The RLF method is the simplified procedure of the heat balance method.[50]

The standard industry method for calculating residential closed loop heat exchangers utilizes the peak load that is entered into any number of commercially available loop design software packages, all based upon the earlier described calculations originally developed by IGSHPA. These software programs include climate bin data libraries and heat pump schedules, often for

[49] C. Pederson, Daniel E. Fisher, Jeffrey D. Spitler, and Richard J. Liesen. "Chapter 2 - Fundamentals of the Heat Balance Methods". In Cooling and Heating Load Calculation Principles. ASHRAE. (1998). Books24x7. http://common.books24x7.com/book/id_18510/book.asp

[50] *See* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., *2009 ASHRAE Handbook - Fundamentals (I-P Edition)*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (2009). Online version available at: http://knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=2554&VerticalID=0

specific manufacturers which automatically select key variables to include in the loop calculations. A bin data calculation example is shown in Table 4. This example is from ClimateMaster's *GeoDesigner* software, which is used for residential closed loop design and estimating annual operating costs. Bin data is keyed to the Outdoor Air Temperature and Annual Weather Hours, with factored space load capacity for each bin portion.

Table 4: Bin calculation data for thermal load calculation

Outdoor Air Temp	Annual Weather Hours	Space Load Btu/Hr	Hot Water Load Btu/Hr	Geo Source Temp	Htg - Clg Capacity Btu/Hr	H.W. Gen Capacity Btu/Hr	Geo Run Time	Geo Operating Cost	Aux Heating Cost	Aux Hot Water Cost
112										
107										
102	1	-1,324	2,326	43	229,517		1%	$0.01		$0.04
97	11	4,486	2,326	39	246,407		2%	$0.20		$0.44
92	39	10,295	2,326	40	245,611		4%	$1.62		$1.56
87	89	16,104	2,326	41	244,811		7%	$5.87		$3.57
82	170	21,913	2,326	42	244,009		9%	$15.43		$6.82
77	277	27,723	2,326	42	243,203		11%	$32.19		$11.11
72	383	30,046	2,326	43	242,880		12%			$15.36
67	483		2,326							$19.37
62	594		2,326							$23.82
57	656	-70	2,326	43	229,807		0%	$0.19		$26.31
52	639	-11,653	2,326	45	234,007		5%	$30.07		$25.63
47	577	-23,236	2,326	44	231,310		10%	$54.48		$23.14
42	571	-34,819	2,326	43	228,629		15%	$81.29		$22.90
37	628	-46,403	2,326	42	225,963		21%	$119.89		$25.19
32	646	-57,986	2,326	41	223,312		26%	$155.06		$25.91
27	557	-69,569	2,326	40	220,676		32%	$161.40		$22.34
22	443	-81,152	2,326	39	218,056		37%	$150.66		$17.77
17	363	-92,735	2,326	38	215,451		43%	$141.94		$14.56
12	321	-104,318	2,326	37	212,861		49%	$142.06		$12.88
7	286	-115,902	2,326	36	210,287		55%	$141.48		$11.47
2	254	-127,485	2,326	35	207,729		61%	$139.05		$10.19
-3	229	-139,068	2,326	34	205,186		68%	$137.58		$9.18
-8	195	-150,651	2,326	34	202,659		74%	$127.68		$7.82
-13	150	-162,234	2,326	33	200,147		81%	$106.40		$6.02
-18	103	-173,818	2,326	32	197,652		88%	$78.75		$4.13
-23	58	-185,401	2,326	31	195,172		95%	$47.58		$2.33
-28	27	-196,984	2,326	30	193,458		100%	$23.21	$1.53	$1.08
-33	10	-208,567	2,326	30	193,458		100%		$2.39	$0.40
	8760							$1,894	$4	$351

Commercial applications are typically driven by occupancy, internal gains generated from lighting, office equipment, etc., and are not solely dependent on climate to estimate annual load durations. Therefore a simple peak load, such as that from ACCA's Manual N calculation, cannot be used to design a commercial ground loop. This has been a significant problem in the growth of the industry due to lack of understanding even by professional mechanical engineers.

The Air Conditioning Contractors of America (ACCA) also provides guidance calculate the heating/cooling load of a building. The heating/cooling load calculation for residential building uses the ACCA's Manual J; this procedure allows for a simple peak heating and cooling but does not provide a load duration and capacity required for designing a closed ground loop. To complete this effort regional climate data is combined with the peak loads using a methodology referred to as a bin data calculation; the peak loads are factored against seasonal averages for the climate region of the installation to determine the annual amount of heat extracted and rejected to a ground loop. Combined with a selection of key geologic properties – thermal conductivity, undisturbed temperature and diffusivity – and heat pump equipment efficiency and required fluid flow rate – allows the designer to verify sufficient ground heat exchanger length while configuring the closed loop system for reasonable pressure drop to allow for least circulation pumping effort.

Monthly peak loads and total cumulative heat gain and loss must be calculated on an annual cycle. Typical software programs available for this effort include Trane's Trace 700 and Carrier's HAP; both are industry standards. Summary load example for a commercial office application is shown in Table 5.

Table 5: Example of monthly total and peak heating and cooling loads

	TOTAL COOLING mBTUh	PEAK COOLING mBTU	TOTAL HEATING mBTUh	PEAK HEATING mBTU
January	42496	191.2	27775	152.6
February	69517	317.5	3129	74.3
March	112596	376.3	728	16.6
April	211083	625.6	0	2.9
May	310819	817.0	0	0.0
June	482441	1051.9	0	0.0
July	511670	1072.4	0	0.0
August	461262	1037.9	0	0.0
September	406614	961.3	0	0.0
October	189947	590.3	0	0.0
November	129956	463.9	1012	2.7
December	74012	300.5	3460	24.8

The table above includes actual building heating and cooling loads, and excludes mechanical system heat. This is the load profile that is entered into the loop design software. Please note the *total* cooling and heating units are in BTU, **not** BTU *per hour*. These monthly durations represent the total energy per month to reject and absorb from the ground loop to meet the demands of the space conditioning application. The peak load per month is still required to determine run factors, another component of commercial loop design. This type of load calculation is mandatory to provide a reasonable comparison of operating costs between competing mechanical systems for commercial applications.

Another issue with commercial loop design contributing to unnecessary higher installation costs is inclusion of mechanical equipment heat gain when entering the data into a commercial ground loop design program. Most of these programs – GLD, GHLEPRO, GchpCalc – require that a heat pump schedule or typical unit efficiency be entered at this point. If the loads already include compressor gain and other impacts, the ground loop will then be significantly oversized to account for additional mechanical equipment loads that do not exist. The total heat rejected to a ground loop, including heat gain from heat pump compressors, is accounted for when using commercial loop design software. The other issue contributing to excessively high closed ground loop installation costs is the treatment of outside air conditioning. If the designer does not use energy reclamation devices, detailed scheduling for outside air management, appropriate controls – occupancy or CO_2 sensors, other – this additional load may adversely impact the size and cost of the ground loop. Typically the reduction in the size and cost of a ground loop more than pays for IAQ and energy reclamation strategies.

Another barrier to industry growth is the assumption by many designers that a building load must be reasonably balanced otherwise backup heating or cooling auxiliary equipment is assumed to be required, further driving up costs for these types of hybrid systems that increase equipment requirements, infrastructure and controls. Unless there is a physical constraint a properly designed heat exchanger even for cooling dominant applications (typical of most commercial projects) will often prove to be less expensive with regards to first costs, and certainly for operating and life cycle cost analysis.

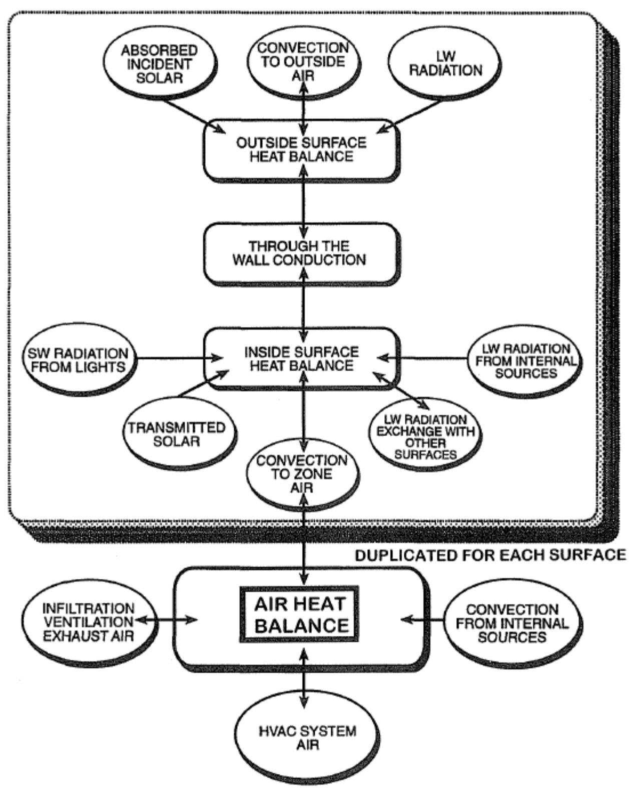

Figure 6. Heat Balance Processes[51]

[51] C. O. Pedersen, Daniel E. Fisher, and Richard J. Liesen. *Development of a Heat Balance Procedure for Calculating Cooling Loads*, ASHRAE Transactions, Vol. 103, Pt. 2, pp. 459-468, (1997).

A3.4. Heat Pump Details

A3.4.1. Heat Pump Characteristics

Several different heat pumps with varying capacities are available for installation in buildings. The capacity of a heat pump is associated with the power of the compressor in the heat pump cycle and the length of heat exchanger components, and how much heat can be delivered from the ground loop to the building load loop at a given speed. The heat pump capacity is associated with the capability of a GHP system to extract heat from the ground. The capacity of a heat pump selected for a building will depend on the maximum heating and cooling building loads as well as on the properties of the heat exchanger loop and ground.[52] The heat pump capacity is measured in BTU/h or in thermal tons (tonnage of thermal capacity – where 1 ton = 1200 BTH/h).

A non-residential building may use more than one heat pump. These heat pumps may have different capacities and serve different rooms or areas. The flexibility to use only some heat pumps at a given time provides an opportunity to have more efficient room and GHP system usage

The efficiency of a heat pump can be quantified using the Coefficient of Performance (COP), Energy Efficiency Ratio (EER), and Seasonal Energy Efficiency Ratio (SEER). The COP is the ratio of the heat transferred by the GHP to the energy (electricity) input for GHP operation. Based on the definition from the U.S. Environmental Protection Agency (U.S. EPA), the EER measures the efficiency of a cooling system when it operates at a specific outdoor temperature (95^{o} F). The value of EER is a ratio between the cooling output (in Btu/h) and the energy (electricity) input (in Watt). The SEER is a measure of central air conditioning efficiency over an entire season and is obtained from the ratio between total cooling (in Btu) and energy input (in watt-hours) in the same period (U.S. EPA). Higher COP, EER or SEER means higher heat pump efficiency.

Geothermal heat pumps may also earn an Energy Star label if they meet the key product criteria (Energy Star Program). The owner of an Energy Star geothermal system may eligible for a federal tax credit. In order to earn an Energy Star label, the system must have COP $\geq$ 3.6 or EER $\geq$ 16.2 for an open-loop system, COP $\geq$ 3.3 or EER $\geq$ 14.1 for a closed-loop system, and COP $\geq$ 3.5 or EER $\geq$ 15 for a DXHP system. More detailed information about the criteria is available at the Energy Star website. [53]

A3.4.2. Hybrid System Details

Large buildings may incorporate a backup or hybrid conventional HVAC system (electric, gas, propane, etc) into to the GHP system, to account for imbalanced heating and cooling loads or extreme weather conditions. Some commercial applications, often cooling dominant, may require an auxiliary cooling device such as a fluid cooler or cooling tower. Residential forced air systems may incorporate a backup electric resistant strip heater, or low temperature backup condensing boiler for water-water heat pumps servicing a hydronic delivery system.

[52] Vanderburg, 2002.

[53] United States Environmental Protection Agency and United States Department of Energy, *Geothermal Heat Pumps Key Product Criteria*, http://www.energystar.gov/index.cfm?c=about.ab_index.

Detailed information (system type, fuel, capacity, power consumption, time of usage) of this hybrid system is needed to assess the adequacy of a GHP system's performance in addressing the building's heating and cooling needs. A system control for the hybrid system is critical to ensure its efficient and effective usage. A GHP system may also use supplemental heat rejection units to overcome the limited cooling capacity of a GHP system. These supplemental units generate additional operating and maintenance costs.[54]

When a detailed installation and operating life cycle analysis is completed for a commercial system it is often rare that a hybrid system makes economic sense compared to a 100% closed loop driven GHP system. The additional hardware, infrastructure and controls cost typically will cost more than just a closed loop that will replace this additional effort. Further, hybrid systems typically increase maintenance and complexity that hamper the effectiveness and intent of a GHP application over the life of the system. Hybrid systems have their place but only when circumstances prevent the full installation of a closed loop ground heat exchanger to be installed.

A3.5. Ground-Source Heat Exchanger Installation Details

A3.5.1. Installation Type

As mentioned in the foreword, there are many different GHP configuration and installation types. Relevant information to the performance evaluation of GHPs from and installation and configuration perspective include whether or not the GHP is a close or open loop system, whether a closed system is has a vertical or horizontal configuration, the heat-exchanger loop length and spacing, heat-exchanger piping details, heat-exchanger fluid details, heat-exchanger fluid flow rate, heat-exchanger temperature, heat pump capacity and efficiency, power and water consumption, and the design of any complementary systems for the GHP system are all components of GHP system design.

A GHP system may be installed during construction of a new building, or it can be retrofitted to an existing building. New and retrofit systems have different installation costs and requirements that may influence the design and installation processes. A retrofit system may install a smaller capacity of GHP system due to difficulties in constructing a new loop system adjacent to or underneath existing structures.

Different loop systems and configurations require different installation procedures and equipment. A vertical configuration requires the drilling of boreholes into which the loop is sunk, while a horizontal configuration requires digging shallow trenches to lay out the loop. Which loop configuration the GHP designer will use is dependent on the availability of land, availability of various heat sources/sinks, thermal properties of the ground or soil, hydrogeology, and the heating/cooling loads of the building. With a large surface land area, horizontal loop configuration is likely more preferable whenever it is feasible. Feasible means that the depth of the horizontal loop can provide sufficient heat transfer from and to the building through all the season. This case may not be the same for a retrofit system since it may require more construction work on the surface to setup the horizontal loop.

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[54] Cenk Yavuzturk and Jeffrey D. Spitler, *Comparative Study of Operating and Control Strategies for Hybrid Ground-Source Heat Pump Systems using a Short Time Step Simulation Model*, ASHRAE Transactions vol. 106 Part 2 pp. 192 - 209, (2000).

A3.5.2. Required Length of Heat Exchanger

The total length of heat exchangers in a GHP system must provide sufficient contact area to provide heat flow by conduction from or to the ground. Longer loop lengths require more drilling or excavation materials and labor, thus loop length heavily influences the capital costs of the GHP system. In a vertical configuration, loop length determines the total depth of borehole drilling, while in a horizontal configuration it determines the size of trench. Kavanaugh and Rafferty (1997) provide a semi-analytical equation to estimate the required length of heat exchanger for commercial and institutional buildings. The length of the heat exchanger is equal to the required length for cooling (L_c) if L_c is longer than the required length for heating (L_h) and vice versa. The required length of heat exchanger for cooling is given by Equation A1.

$$L_c = \frac{q_a * R_{ga} + (q_{lc} - 3.41W_c) * (R_b + PLF_m * R_{gm} + R_{gd} * F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \qquad \text{(A1)}$$

Similarly, the required length of heat exchanger for heating is given Equation 2.

$$L_h = \frac{q_a * R_{ga} + (q_{lh} - 3.41W_h) * (R_b + PLF_m * R_{gm} + R_{gd} * F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \qquad \text{(A2)}$$

where,

L_c = required bore length for cooling (ft)
L_h = required bore length for heating (ft)
F_{SC} = short-circuit heat loss factor
PLF_m = part-load factor during design month
q_a = net annual average heat transfer to the ground (Btu/h)
q_{lc} = building design cooling block load (Btu/h)
q_{lh} = building design heating block load (Btu/h)
R_{ga} = effective thermal resistance of the ground, annual pulse (h.ft.^{o}f/Btu)
R_{gd} = effective thermal resistance of the ground, daily pulse (h.ft.^{o}f/Btu)
R_{gm} = effective thermal resistance of the ground, monthly pulse (h.ft.^{o}f/Btu)
R_b = thermal resistance of bore (h.ft.^{o}f/Btu)
t_g = undisturbed ground temperature (^{o}F)
t_p = temperature penalty for interference of adjacent bores (^{o}F)
t_{wi} = liquid temperature at heat pump inlet (^{o}F)
t_{wo} = liquid temperature at heat pump outlet (^{o}F)
W_c = power input at design cooling load (W)
W_h = power input at design heating load (W)

A3.5.3. Total Borehole Depth and Spacing

Total borehole depth refers to the cumulative depth of borehole drilling needed to install a vertical loop configuration for a GCHP or GWHP system. The total borehole depth is needed to estimate the total installation cost of vertical GCHP and GWHP systems because the drilling cost is generally measured in $/ft of borehole. The depth of individual boreholes will be dependent on the total length of heat exchanger required (associated with the soil thermal conductivity and heating/cooling load), the availability of land for vertical borehole installation, land availability, depth of groundwater source (for a GWHP system), and the depth to bedrock.

The spacing between heat-exchanger loops has to be selected carefully to minimize interference in the heat transfer process between the loop and the heat sources or heat sink (thermal short-circuiting). Most design tools for GCHP systems incorporate a correction factor to account for thermal short circuiting between the inflow and outflow tubes of the heat exchange loop. One advantage of incorporating heat exchangers into civil engineering systems is that the spacing of the inflow and outflow tubes can be greater.

Important variables that determine the installation cost of vertical closed-loop ($/ft of bore) are the soil and rock classification, and the number, size, spacing, and depth of the boreholes. The lithology of the site will dictate drilling technique and borehole completion technique. Some common techniques are down- hole-hammer (for hard rocks) and rotary drilling techniques (for soft to medium rocks and soils). Water, grout, or porous backfill may fill the gap between the loop and the borehole wall for borehole completion.[55] The fill material provides heat transfer between the borehole wall and the U-tube. The most common material for grouting backfill is a thermal grout composed of fine quartz sand/salt and bentonite, providing high thermal conductivity for heat transfer and low hydraulic conductivity to prevent contamination inside or under the borehole. Other variables that influence the installation costs of the ground loop are the contractors' travel costs, disposal of bore cuttings, labor rates, and non-standard header arrangements.[56]

A3.5.4. Trench Dimensions

Trenches are used for horizontal loop configurations. The trench dimensions (depth, width, and length) depend on the heating/cooling load, land availability to setup the trench, ground/soil thermal conductivity, and heat capacity. The trench must be below the frost-depth at a given geographic location, and should be below the depth at which there are significant changes in temperature due to atmospheric interaction. A deep trench provides sufficient thermal storage and soil moisture content to protect the loop from winter frosts. If the trench is primarily used as a heat source during the winter, the trench should be shallow enough for the penetration of solar and atmospheric heat to restore the heat around the loop while still avoiding frost penetration.

The trenching costs will depend on the trench size needed to supply the heat exchange for a building. A horizontal closed-loop system can use deep and narrow trenches or wide and shallow trenches. A chain type trencher digs narrow trenches while a backhoe digs the wider ones.[57] The cost of a backhoe and operator ($/hour) depends on local contractors and market conditions. The total trenching cost is the multiplication of the required number of backhoe hours and its costs per hour. Some operators may include additional "move-on" and "move-off" costs in the total trenching costs.[58] Table 6 shows a chart to determine the number of backhoe hours required to

[55] Banks, 2008.
[56] Kavanaugh and Rafferty, 1997.
[57] Kavanaugh and Rafferty, 1997.
[58] James A. Thomson, *2006 National Plumbing and HVAC Estimator*, Craftsman Book Company, Carlsbad – Ca, (2006).

create 100 linear ft of trench on average soil (dirt, soft clay, or gravel mixed with rocks). The trench walls have 90 degree angles. The trenching costs include trenching, backfilling, and compacting costs. Efforts which are required to maintain safety, such as shoring or beveling of trenches or pits should also be accounted for in cost estimates. Ground water may be encountered during the loop installation process if shallow water conditions exist, which may lead to additional costs being incurred.

Table 6: Required Backhoe-Hours for Trenching[59]

Trench Depth (feet)	**Trench width (feet)**					
	1	**2**	**3**	**4**	**5**	**6**
2	2.6	5.1	7.7	10.2	12.8	15.3
3	3.8	7.7	11.5	15.3	19.2	23.0
4	5.1	10.2	15.3	20.4	25.6	30.7
5	6.4	12.8	19.2	25.6	32.0	38.3
6	7.7	15.3	23.0	30.7	38.3	46.0

A3.5.5. Heat Exchanger Piping Data

The piping used in the heat exchanger loop can have a significant impact on the performance of the GHP. The main parameters needed to characterize the piping are the material type, inside diameter, wall thickness, and the distance between the upward and downward portions of the loop. GHP systems generally use High Density Polyethylene (HDPE) or Medium Density Polyethylene (MDPE). Copper pipe has been used in direct expansion systems because of its higher thermal conductivity. However, copper is particularly susceptible to corrosion when embedded in the ground and is often prohibited by state codes. The designer's choice of piping depends on the thermal conductivity of the soil and the heating/cooling loads of the building.

A3.5.6. Heat Exchanger Fluid Data

The heat exchanger fluid transfers the heat from/to the heat sources/heat sink. This is different from the refrigerant fluid within the heat pump, except in the case of direct expansion GHP systems, where the fluid within the heat pump is circulated directly in a heat exchanger loop embedded in the ground. The heat exchanger fluid is circulated through closed-loop GHP systems and is typically an antifreeze solution, which is needed to prevent freezing during heat extraction from the ground. Some important criteria for the circulating fluid are the heat transfer capability, viscosity, safety for the environment (toxicity, flammability, pollution risk in the case of leakage), cost, and impact to the system (corrosivity). Regulations also influence the selection of circulating fluids for a GHP system. For example, ethylene glycol is banned in the US due to its toxicity in high concentrations, although it is still commonly used in Europe.[60]

A3.5.7. Water Consumption

[59] Thomson, 2006.

[60] Karen Den Braven, *Survey of geothermal heat pump regulations in the United States*. In the Proceedings of 2nd Stockton International Geothermal Conference, 16 - 17 March 1998. (1998).

Information about the water consumption of GHP system helps the comparison of water usage between the GHP and other HVAC systems. The water pumping rate should be monitored if an open-loop GHP system is incorporated into a building.

A4. Decision Data

A4.1. Capital and Installation Costs

The cost of a heat pump system and the installation of the ground loop is an important parameter from the implementation perspective. These costs will depend on the size of a project, and the difficulties encountered on the installation. There are several government subsidies can be used to used to pay for the initial installation costs. The up-front cost is an important barrier, so it is an important piece of data. However, it should be noted that the long-term cost savings can mitigate a high up-front cost.

A4.2. Surface Land Availability and Environmental Impact Issues

The surface land availability, along with the ground temperature, influences the configuration of a GHP system for a given project. A horizontal loop system may provide lower construction costs because it requires only trenching instead of bore hole drilling. However, such a system requires more surface land availability. Drilling may also not be possible in some areas because of contaminated soils or groundwater.

A4.3. Groundwater Availability and Environmental Impact Issues

The feasibility of using a groundwater heat pump system depends on its physical availability, legal resource ownership of the groundwater, and regulations concerning ground/surface water usage. In most jurisdictions for closed loop systems there are no legal rights issues as long as the ground loop is installed within the land boundaries of the project. In an open loop GWHP system, information about the mineral content of the water entering and exiting the open loop is critical to prevent pollution at the water discharge point (i.e., a pond or aquifer). The mineral content may also be critical for the estimation of mineral deposition, corrosion (if metal pipes are used), or other damage risks which may occur to the GWHP system.

APPENDIX B: GHP DATA COLLECTION SPREADSHEET

Worksheet 0 – Project Details

Location	
Date of Collection	
Building Type	
Age of the GHP System	

Worksheet 1 – Electricity and Cost Data

DATA		Data Collection Method	Notes
Electricity Consumption Data			
1	Actual Electricity Usage		
2	Actual Electricity Peak Demand		
3	Complementary System Energy Usage		
4	Complementary System Peak Demand		
Economic Data			
1	Operating Cost		
2	Maintenance Cost		
3	Historic Operating Cost		
4	Historic Maintenance Cost		
5	Cost Savings		

Notes: The data can be input on a daily, monthly, or annual basis depending on availability

Date	Actual Electricity Usage	Actual Electricity Peak Demand	Complementary System Energy Usage	Complementary System Peak Demand	Operating Cost	Maintenance cost	Historic operating cost	Historic maintenance cost	Cost Savings
	(kWh)	(kW)	(kWh or m^3)	(kW or m^3)	($)	($)	($)	($)	($)

Worksheet 2 – Performance Data

	DATA	Data Collection Method	Notes
Performance Data			
1	Entering Heat Exchange Fluid Temperature		
2	Exiting Heat Exchange Fluid Temperature		
3	Heat Exchanger Fluid Flow Rate		
4	Coefficient of Performance		
5	Ground/Borehole Temperature		
6	Groundwater Pumping Rate		

Notes: The data can be in annual or monthly basis depending on its availability

Date	Entering heat exchange fluid temperature	Exiting heat exchange fluid temperature	Heat exchanger fluid flow rate	Coefficient of Performance	Average groundwater or borehole temperature	Groundwater pumping rate
	(°C)	(°C)	(LPM)		(°C)	(LPM)

Worksheet 3a – Design Data: Geology

	DATA	Data Collection Method	Value/Description	Notes
Thermogeologic Setting				
1	Average Ground Temperature			Celsius
2	Geothermal Gradient			^{o}C/1000m
3	Frost Depth			m
4	Groundwater Temperature			Celsius
5	Depth to Groundwater			m
Geology				
1	Soil/Rock Layer Thickness			meters
2	Soil/Rock Type (UCSC classification)			
3	Soil/Rock Mineralization			
4	Gravimetric Water Content			percent
5	Porosity			percent
6	Hydraulic Conductivity or Permeability			percent
7	Layer Thermal Conductivity			W/m°C
				W/m°C
				W/m°C
				W/m°C
8	Layer Volumetric Heat Capacity			
9	Average Borehole Thermal Conductivity			W/m^{o}C
10	Average Borehole Thermal Diffusivity			m^2/s
11	Average Borehole Volumetric Heat Capacity			J/(cm^{3o}C)

Worksheet 3b – Design Data: Building

DATA		Data Collection Method	Value/Description	Notes/Units
Building Characteristics				
1	Building Type/Purpose			Commercial/Residential
2	Geographical Setting			City/rural
3	Indoor Design Conditions			°C temp; % humidity
4	Climate Setting			
5	Energy source			
6	Complementary heating system			
7	Complementary cooling system			
Building Load				
1	Maximum Heating Load			tons
2	Maximum Cooling Load			tons
Heat Pump System				
1	Number of Heat Pumps			
2	Heat Pump Manufacturer/Model			
3	Heat Pump Size/Capacity Heating			
4	Heat Pump Size/Capacity Cooling			
5	Manufacturer Heat Pump Efficiency			
6	Heat Distribution System			

Month	Heating Load (tons)	Cooling Load (tons)
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

Notes: Data requirement for the heating/cooling load calculation (including local climate condition) is available in the ACCA's Manual J (for residential building) and Manual N (for non-residential building).

Worksheet 3c – Design Data: Loop

	DATA	Data Collection Method	Value/Description	Notes/Units
System and Energy Consumption Characteristics				
1	Installation Type?			
2	Designed Power Consumption			kW
3	Designed Water Consumption			LPM
Heat Exchanger System Design				
1	Type of Heat Source/Sink			
2	Loop Type			
3	Loop Configuration			
4	Loop Length			m
5	Loop Pipe Diameter			mm
6	Loop Pipe Material			
7	Number of Pipes in a Trench			
8	Circulating Fluid Type			
9	Designed Circulating Fluid Temperature			(^{o}C) Temperature of the working fluid
	a.Entering Temperature			(^{o}C) Entering the heat pump
	b.Exiting Temperature			(^{o}C) Exiting the heat pump
10	Designed Fluid Flow Rate			LPM
11	Re-Injection Wells?			
Construction Work Requirement				
1	Number of Boreholes			
2	Total Borehole Depth			m
3	Borehole Diameter			mm
4	Grouting Materials			
5	Cut Depth			m
6	Trench Depth			m
7	Trench Width			m

Worksheet 4 – Decision Data

DATA		Data Collection Method	Value/Description	Notes/Units
Cost Element				
1	Capital Cost			
	a.Heat Pump Cost			Total cost for heat pump
	b.Drilling/Trenching Cost			
	c.Design Cost			
	d.Piping System Cost			
	e.Data Collection Cost			
2	Payback Period			
Environmental Impact Parameter				
1	Surface/Groundwater Temperature		Only for Open Loop Configuration	
2	Aquifer Condition			
3	Surface/Groundwater Mineral Content		Only for Open Loop Configuration	
Resource Availability				
1	Surface Land Area			m^2
2	Groundwater Availability			

APPENDIX C: EXAMPLE GHP DATA COLLECTION SPREADSHEET

Worksheet 0 – Project Details

JUNIOR HIGH SCHOOL	
Location	Ft. Collins Colorado
Date of Collection	Oct-10
Building Type	Commercial - School
Age of the GHP System	3 years

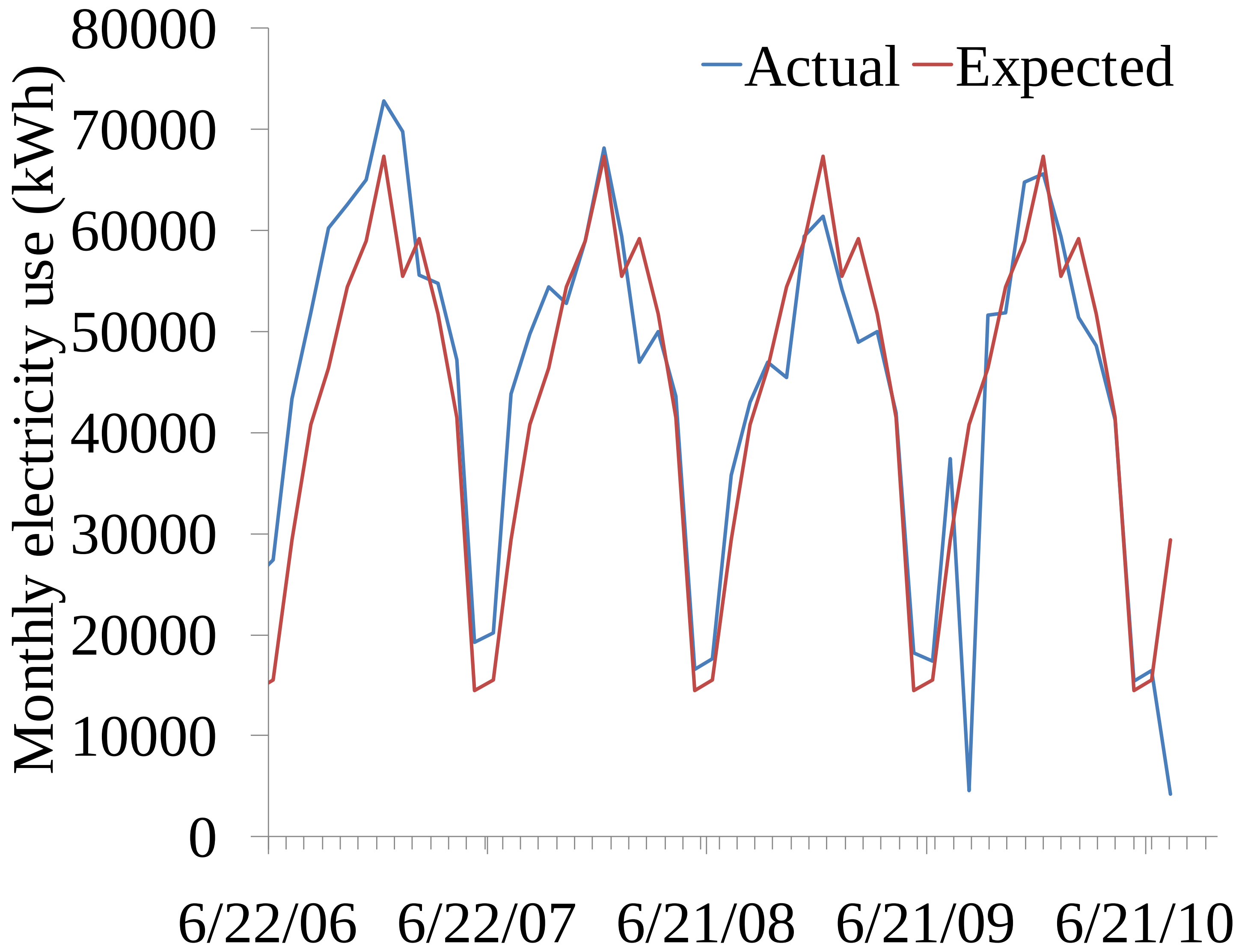
Worksheet 1 – Electricity and Cost Data

	DATA	Data Collection Method	Notes
Electricity Consumption Data			
1	Actual Electricity Usage	Electricity for full building (not individual heat pumps)	
2	Actual Electricity Peak Demand	Electricity for full building (not individual heat pumps)	
3	Complementary System Energy Usage	Gas boilers	
4	Complementary System Peak Demand	Gas boilers	
Economic Data			
1	Operating Cost	Electricity for full building (not individual heat pumps)	
2	Maintenance Cost	Not collected	
3	Historic Operating Cost	Not available	
4	Historic Maintenance Cost	Not available	
5	Cost Savings	Not available	

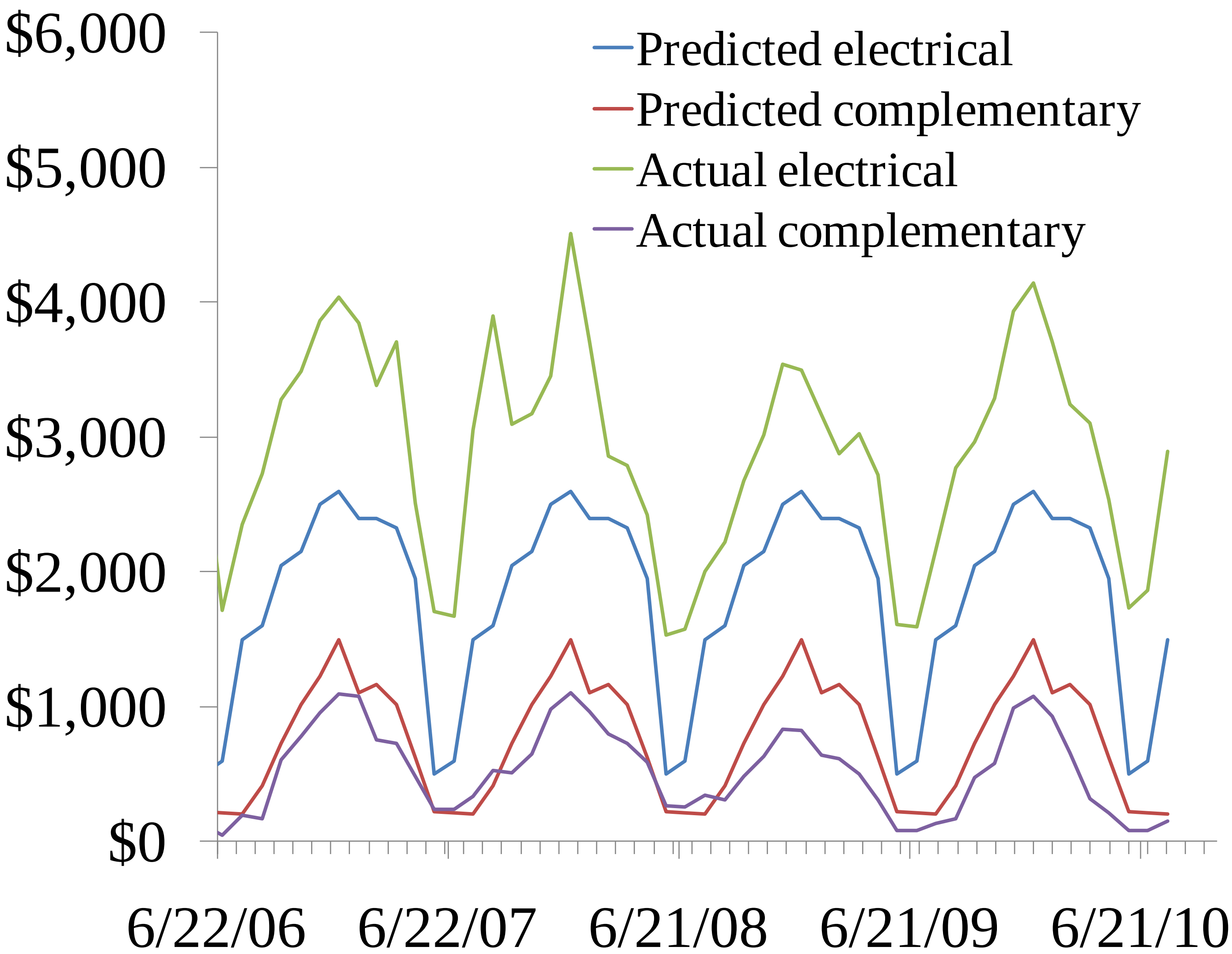
Notes: The data can be input on a daily, monthly, or annual basis depending on availability

Date	Actual Electricity Usage	Actual Electricity Peak Demand	Complementary System Energy Usage (Gas Vol.)	Complementary System Peak Demand (Gas Vol.)	Operating Cost	Maintenance cost	Historic operating cost	Historic maintenance cost	Cost Savings	Actual gas costs ($)	Expected Electrical Energy	Expected Peak Electric	Model gas usage	Predicted electrical costs ($)	Predicted gas costs ($)
	(kWh)	(kW)	(m^3)	(m^3)	($)	($)	($)	($)	($)	($)	(kWh)	(kW)	kWh/hr	($)	($)
6/1/2006	25600	222	0.56		2922.15					128.93	14518	35	3.722157	500	220
7/1/2006	27400	155.4	0.12		1711.58					42.81	15546	35	3.66354	600	210
8/1/2006	43400	220	0.75		2354					196	29354	218	11.43025	1500	200
9/1/2006	51800	200	1.18		2730.72					166	40814	230	22.86049	1600	415
10/1/2006	60200	268	1.73		3274.61					602	46381	270	32.82532	2050	725
11/1/2006	62600	288	2.47		3488.54					779	54426	287	45.72098	2150	1015
12/1/2006	65000	298	3.35		3865.56					954	58982	307	52.16882	2500	1225
1/1/2007	72800	304	5.46		4036.83					1098.91	67344	308	66.41266	2600	1500
2/1/2007	69800	308	4.48		3843					1080	55511	304	53.92732	2400	1100
3/1/2007	55600	282	2.42		3384					752	59164	291	55.39273	2400	1165
4/1/2007	54800	276	2.65		3707					726	51720	294	43.96249	2323	1015
5/1/2007	47200	216	1.62		2508					483	41544	252	28.72216	1950	625
6/1/2007	19200	216	0.00		1704					236	14518	35	3.722157	500	220
7/1/2007	20200	215.6	0.00		1671.13					237.67	15546	35	3.66354	600	210
8/1/2007	43800	240	0.43		3053					335	29354	218	11.43025	1500	200
9/1/2007	49800	230	0.82		3901					531	40814	230	22.86049	1600	415
10/1/2007	54400	218	1.05		3096					511	46381	270	32.82532	2050	725
11/1/2007	52800	270	1.97		3173					648	54426	287	45.72098	2150	1015
12/1/2007	59000	288	3.87		3448					980	58982	307	52.16882	2500	1225
1/1/2008	68200	280	4.52		4506.83					1102.74	67344	308	66.41266	2600	1500
2/1/2008	59400	282	3.59		3704					967	55511	304	53.92732	2400	1100
3/1/2008	47000	266	2.61		2859					800	59164	291	55.39273	2400	1165
4/1/2008	50000	232	2.16		2787					726	51720	294	43.96249	2323	1015
5/1/2008	43600	202	1.32		2419					587	41544	252	28.72216	1950	625
6/1/2008	16600	202	0.00		1531					261	14518	35	3.722157	500	220
7/1/2008	17600	201.6	0.00		1576.93					260.1	15546	35	3.66354	600	210
8/1/2008	35800	202	0.43		2003					345	29354	218	11.43025	1500	200
9/1/2008	43000	202	0.83		2220					310	40814	230	22.86049	1600	415
10/1/2008	47000	226	1.24		2676					487	46381	270	32.82532	2050	725
11/1/2008	45400	242	2.39		3014					628	54426	287	45.72098	2150	1015
12/1/2008	59400	276	4.02		3543					834	58982	307	52.16882	2500	1225
1/1/2009	61400	288	3.98		3498.51					821.18	67344	308	66.41266	2600	1500
2/1/2009	54200	270	3.24		3164					640	55511	304	53.92732	2400	1100
3/1/2009	49000	266	3.04		2875					611	59164	291	55.39273	2400	1165
4/1/2009	50000	276	2.37		3024					500	51720	294	43.96249	2323	1015
5/1/2009	42000	226	1.35		2722					312	41544	252	28.72216	1950	625
6/1/2009	18200	202	0.00		1612					78	14518	35	3.722157	500	220
7/1/2009	17400	201.5	0.00		1596.55					78.44	15546	35	3.66354	600	210
8/1/2009	37400	200	0.43		2158					130	29354	218	11.43025	1500	200
9/1/2009	4600	198	0.82		2772					172	40814	230	22.86049	1600	415
10/1/2009	51600	298	2.10		2961					475	46381	270	32.82532	2050	725
11/1/2009	51800	258	2.64		3283					576	54426	287	45.72098	2150	1015
12/1/2009	64800	320	5.05		3934					989	58982	307	52.16882	2500	1225
1/1/2010	65600	296	5.11		4144.88					1077.98	67344	308	66.41266	2600	1500
2/1/2010	59400	298	4.45		3708					933	55511	304	53.92732	2400	1100
3/1/2010	51400	264	3.04		3245					659	59164	291	55.39273	2400	1165
4/1/2010	48600	238	1.75		3106					314	51720	294	43.96249	2323	1015
5/1/2010	41200	222	0.99		2533					213	41544	252	28.72216	1950	625
6/1/2010	15400	224	0.00		1730.66					78	14518	35	3.722157	500	220
7/1/2010	16400	224	0.00		1863					78.32	15546	35	3.66354	600	210
8/1/2010	4200	236	0.47		2892					148	29354	218	11.43025	1500	200

Total Electricity Graph



Total Cost Graph



Worksheet 2 – Performance Data

	DATA	Data Collection Method	Notes
	Performance Data		
1	Entering Heat Exchange Fluid Temperature	See below	
2	Exiting Heat Exchange Fluid Temperature	See below	
3	Heat Exchanger Fluid Flow Rate	Not measured	
4	System thermal conductiity		
5	Coefficient of Performance	Not measured	
5	Ground/Borehole Temperature	Not measured	
6	Groundwater Pumping Rate	Not applicable	

Room 520, Upstairs, Waterfurnace E-Series E035

Flow rate	26.53	LPM
Fluid mass density	1000	kg/m^3
Specific Heat of Fluid	4.186	kJ/kg°C
Heating Elec Consumed (Room 520 - E035)	8.60	kW
Cooling Elec Consumed (Room 520 - E035)	6.48	kW

Date	Entering heat exchange fluid temperature	Exiting heat exchange fluid temperature	Heat exchanger fluid flow rate	Thermal Energy Delivered	Electrical Energy supplied	Coefficient of Performance	Average groundwater or borehole temperature	Groundwater pumping rate
	(°C)	(°C)	(LPM)	(kW)	(kW)		(°C)	(LPM)
5/9/11 9:53	16	27.5	26.5	21.29	6.48	3.3	N/A	N/A
5/9/11 9:58	11.5	29.5	26.5	33.32	6.48	5.1	N/A	N/A
5/9/11 10:03	12.5	34.5	26.5	40.72	6.48	6.3	N/A	N/A
5/9/11 10:08	14	34	26.5	37.02	6.48	5.7	N/A	N/A
5/9/11 10:13	14.5	33.5	26.5	35.17	6.48	5.4	N/A	N/A
5/9/11 10:18	15	33	26.5	33.32	6.48	5.1	N/A	N/A
5/9/11 10:23	15.5	32.5	26.5	31.47	6.48	4.9	N/A	N/A
5/9/11 10:28	16	32	26.5	29.61	6.48	4.6	N/A	N/A
5/9/11 10:33	16.5	31.5	26.5	27.76	6.48	4.3	N/A	N/A
5/9/11 10:38	17	31.5	26.5	26.84	6.48	4.1	N/A	N/A
5/9/11 10:43	17	31	26.5	25.91	6.48	4.0	N/A	N/A
5/9/11 10:48	17.5	30.5	26.5	24.06	6.48	3.7	N/A	N/A
5/9/11 10:53	17.5	30.5	26.5	24.06	6.48	3.7	N/A	N/A
5/9/11 10:58	18	30	26.5	22.21	6.48	3.4	N/A	N/A
5/9/11 11:03	18	30	26.5	22.21	6.48	3.4	N/A	N/A
5/9/11 11:08	18.5	30	26.5	21.29	6.48	3.3	N/A	N/A
5/9/11 11:13	18.5	29.5	26.5	20.36	6.48	3.1	N/A	N/A
5/9/11 11:18	18.5	29	26.5	19.43	6.48	3.0	N/A	N/A
5/9/11 11:23	19	29	26.5	18.51	6.48	2.9	N/A	N/A
5/9/11 11:28	19	28.5	26.5	17.58	6.48	2.7	N/A	N/A
5/9/11 11:33	19	28.5	26.5	17.58	6.48	2.7	N/A	N/A

Worksheet 3a – Design Data: Geology

	DATA	Data Collection Method	Value/Description	Notes
Thermogeologic Setting				
1	Average Ground Temperature		14	Celsius
2	Geothermal Gradient		15.240	^{o}C/1000m
3	Frost Depth		1	m
4	Groundwater Temperature		11	Celsius
5	Depth to Groundwater		1	m
Geology				
1	Soil/Rock Layer Thickness		0 to 3 m	meters
			3 to 5.5 m	
			5.5 to 15.25 m	
			15.25 to 91.5 m	
2	Soil/Rock Type (UCSC classification)		SC	
			SP	
			CH	
			CH - Shale	
3	Soil/Rock Mineralization		Quartz/Clay minerals	
			Quartz	
			Clay minerals	
			Clay minerals	
4	Gravimetric Water Content		Unknown	percent
			Unknown	
			Unknown	
			Unknown	
5	Porosity		Unknown	percent
			Unknown	
			Unknown	
			Unknown	
6	Hydraulic Conductivity or Permeability		Unknown	percent
			Unknown	
			Unknown	
			Unknown	
7	Layer Thermal Conductivity		Unknown	W/m°C
			Unknown	W/m°C
			Unknown	W/m°C
			Unknown	W/m°C
8	Layer Volumetric Heat Capacity		Unknown	
			Unknown	
			Unknown	
			Unknown	
9	Average Borehole Thermal Conductivity		1.49	W/m°C
10	Average Borehole Thermal Diffusivity		6.4525E-07	m^2/s
11	Average Borehole Volumetric Heat Capacity		2.013	J/(cm^{3}°C)

Worksheet 3b – Design Data: Building

DATA		Data Collection Method	Value/Description	Notes/Units
Building Characteristics				
1	Building Type/Purpose	School - Commercial		Commercial/Residential
2	Geographical Setting	Urban		City/rural
3	Indoor Design Conditions	20 °C		
4	Climate Setting	High plains, arid		
5	Energy Source	Grid electric		
6	Complementary Heating System	Boiler		
7	Complementary Cooling System	None		
Building Load				
1	Maximum Heating Load	Not available		tons
2	Maximum Cooling Load	Not available		tons
Heat Pump System				
1	Number of Heat Pumps	73		
2	Heat Pump Manufacturer/Model	Premier and E-Series		
3	Heat Pump Size/Capacity Heating	2.2 to 11.4		kWh/hr
4	Heat Pump Size/Capacity Cooling	2.1 to 8.7		kWh/hr
5	Manufacturer Heat Pump Design COP	3 (heating) to 12 (cooling)		
6	Heat Distribution System	Air handlers, local		

Month	Heating Load (tons)	Cooling Load (tons)
January	NA	NA
February	NA	NA
March	NA	NA
April	NA	NA
May	NA	NA
June	NA	NA
July	NA	NA
August	NA	NA
September	NA	NA
October	NA	NA
November	NA	NA
December	NA	NA

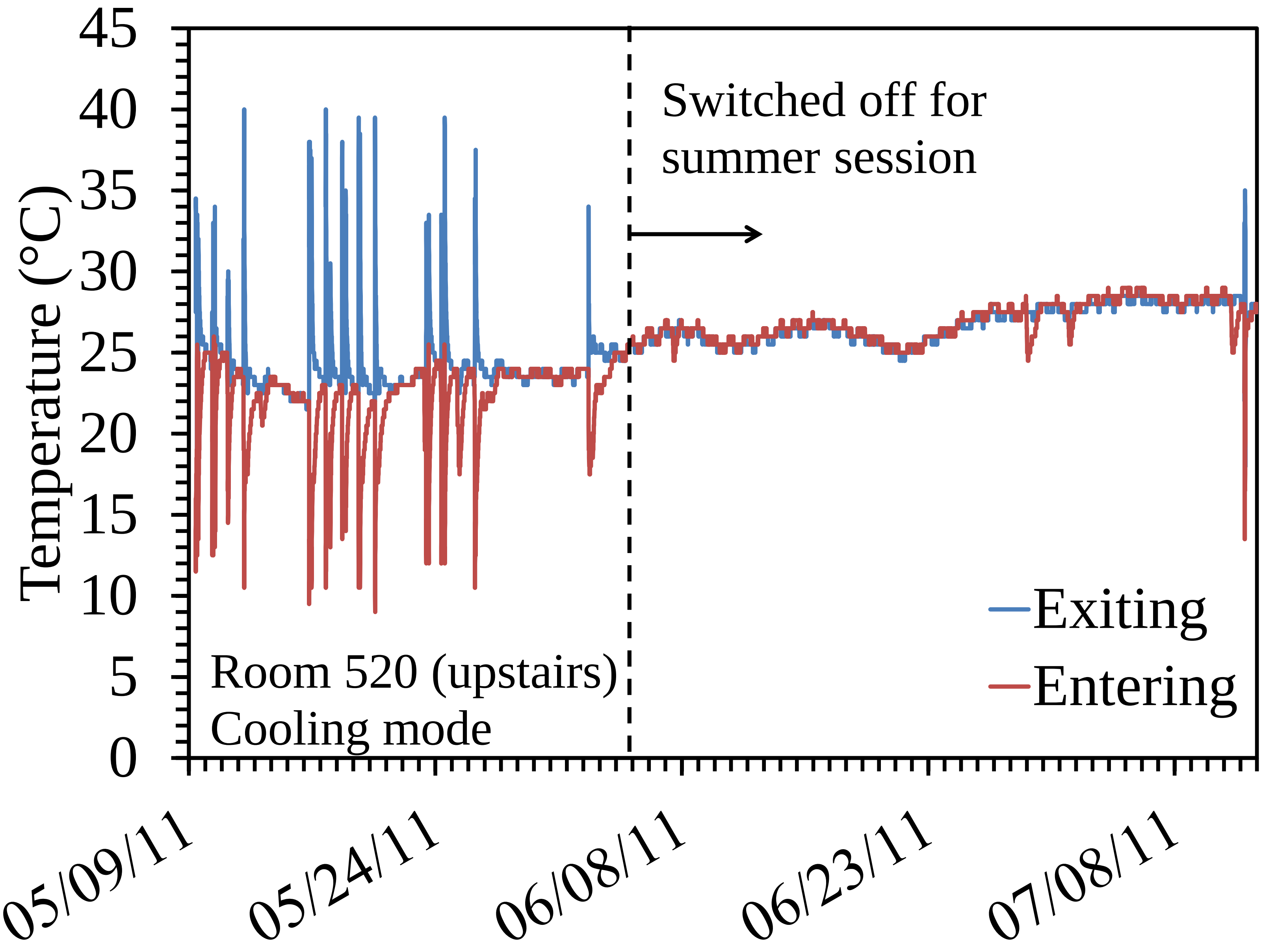
Notes: Data requirement for the heating/cooling load calculation (including local climate condition) is available in the ACCA's Manual J (for residential building) and Manual N (for non-residential building).

Worksheet 3c – Design Data: Loop

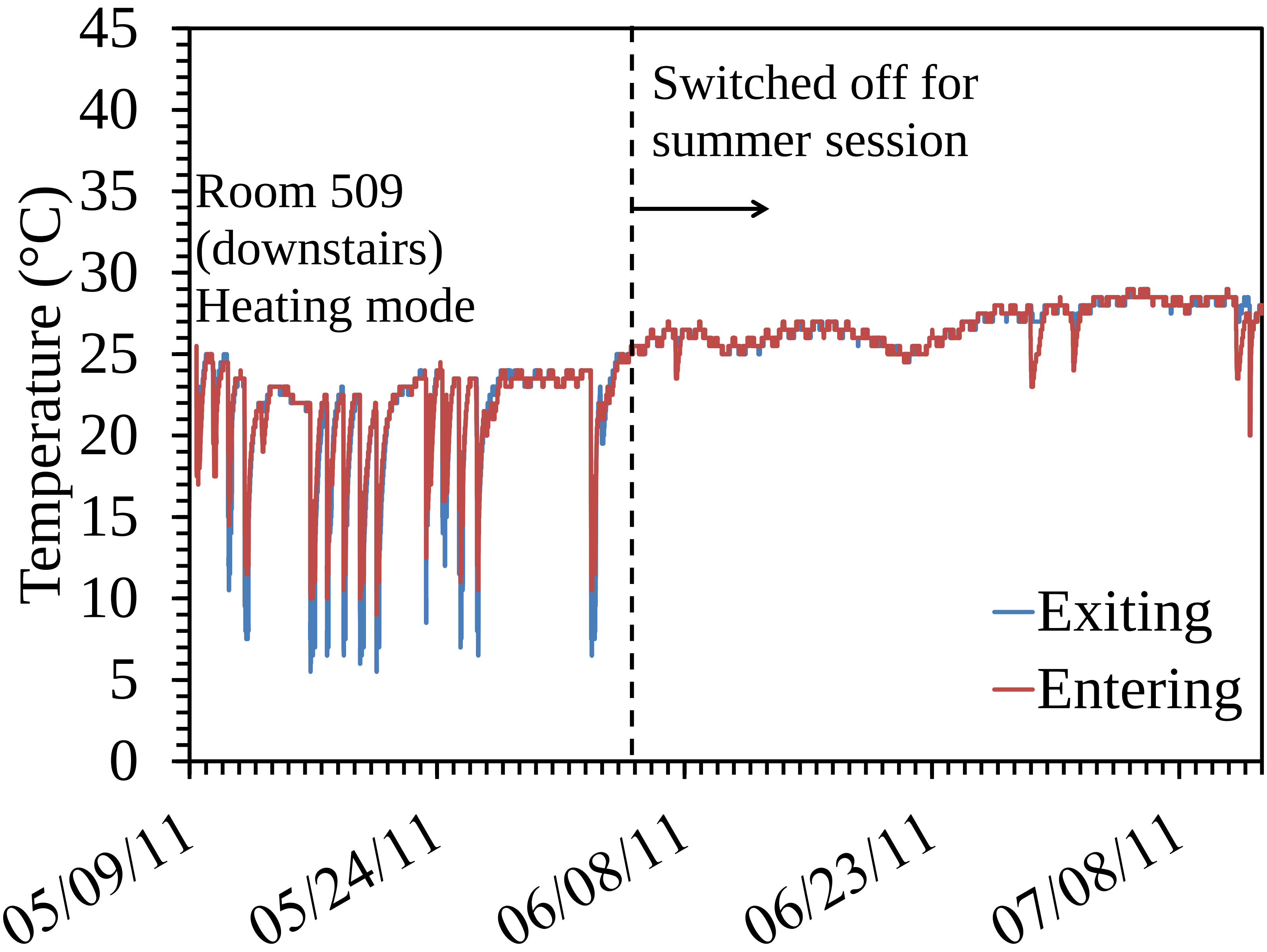
	DATA	Data Collection Method	Value/Description	Notes/Units
System and Energy Consumption Characteristics				
1	Installation Type?	Design documents	New	
2	Designed Power Consumption	Design documents	300	kW
3	Designed Water Consumption	Design documents	N/A	
Heat Exchanger System Design				
1	Type of Heat Source/Sink	Design documents	GSHP	
2	Loop Type	Design documents	Closed loop	
3	Loop Configuration	Design documents	Vertical boreholes	
4	Loop Length	Design documents	100 m x 98	,
5	Loop Pipe Diameter	Design documents	25.4	mm
6	Loop Pipe Material	Design documents	DriscoPlex 5300 (Polyethylene)	
7	Number of Pipes in a Trench	N/A	N/A	
8	Circulating Fluid Type	Design documents	Propylene glycol and water	
9	Designed Circulating Fluid Temperature	Design documents		
	a.Entering Water Temperature	Design documents	10-25 (cooling) to 10-15.6 (heating)	(°C) Entering the heat pump (expected)
	b.Exiting Temperature	Design documents	32.2 (cooling) to 1.67 (heating)	(°C) Exiting the heat pump
10	Designed Fluid Flow Rate	N/A	9.1 to 63.7	LPM
11	Re-Injection Wells?	N/A	N/A	
Construction Work Requirement				
1	Number of Boreholes	Design documents	98	
2	Total Borehole Depth	Design documents	91.44	m
3	Borehole Diameter	Design documents	120.65	mm
4	Grouting Materials	Design documents	Enlink Geothermal Grout	
5	Cut Depth	N/A	NA	
6	Trench Depth	N/A	NA	
7	Trench Width	N/A	NA	

Worksheet 4 – Decision Data

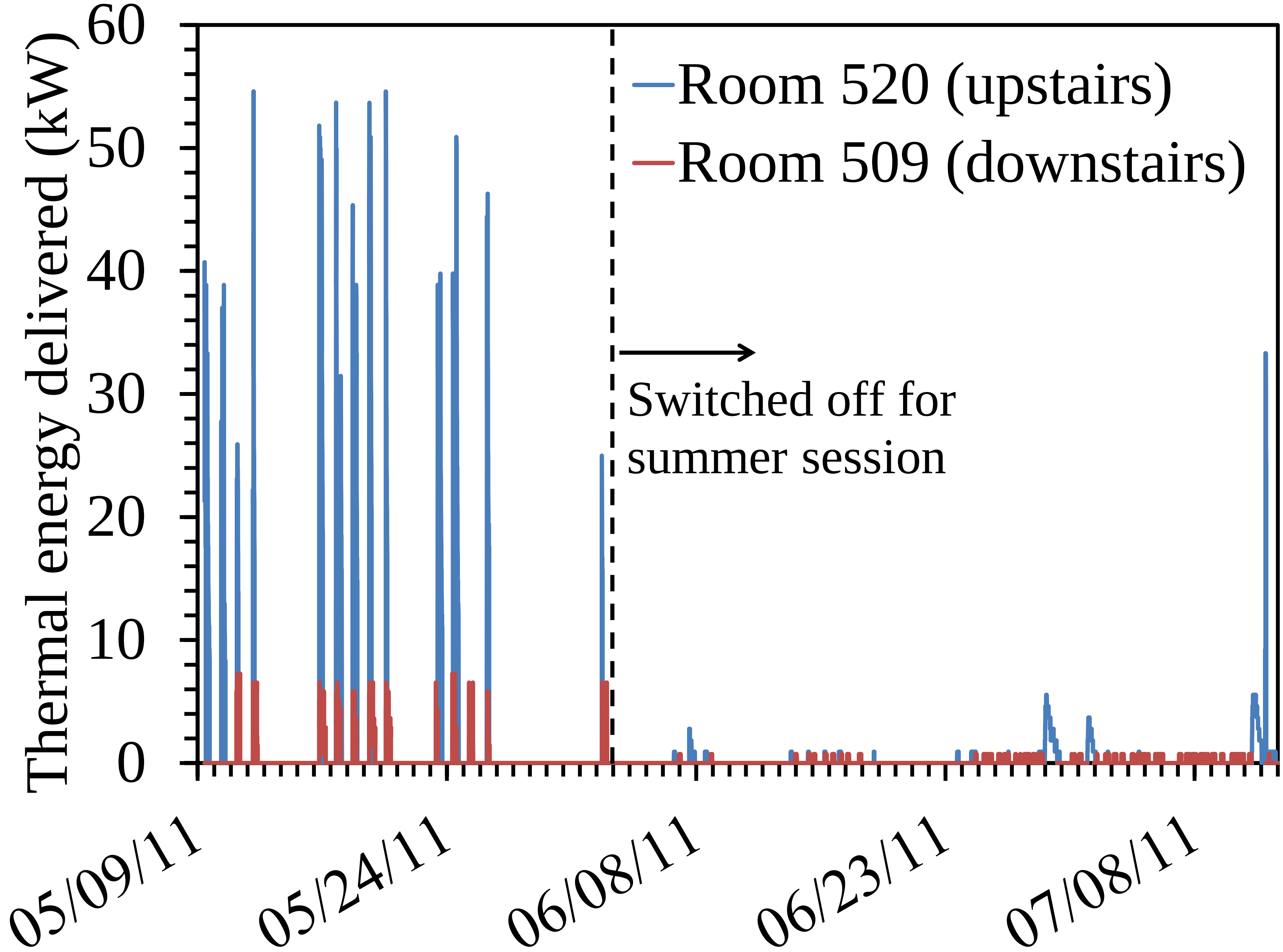
DATA		Data Collection Method	Value/Description	Notes/Units
Cost Element				
1	Capital Cost	Not available	Not available	
	a.Heat Pump Cost	Not available	Not available	Total cost for heat pump
	b.Drilling/Trenching Cost	Not available	Not available	
	c.Design Cost	Not available	Not available	
	d.Piping System Cost	Not available	Not available	
	e.Data Collection Cost	Not available	Not available	
2	Payback Period	Not available	Not available	
Environmental Impact Parameter				
1	Surface/Groundwater Temperature	Unknown	Only for Open Loop Configuration	
2	Aquifer Condition	Unknown		
3	Surface/Groundwater Mineral Content	Unknown	Only for Open Loop Configuration	
Resource Availability				
1	Surface Land Area	Unknown		m^2
2	Groundwater Availability	Unknown		



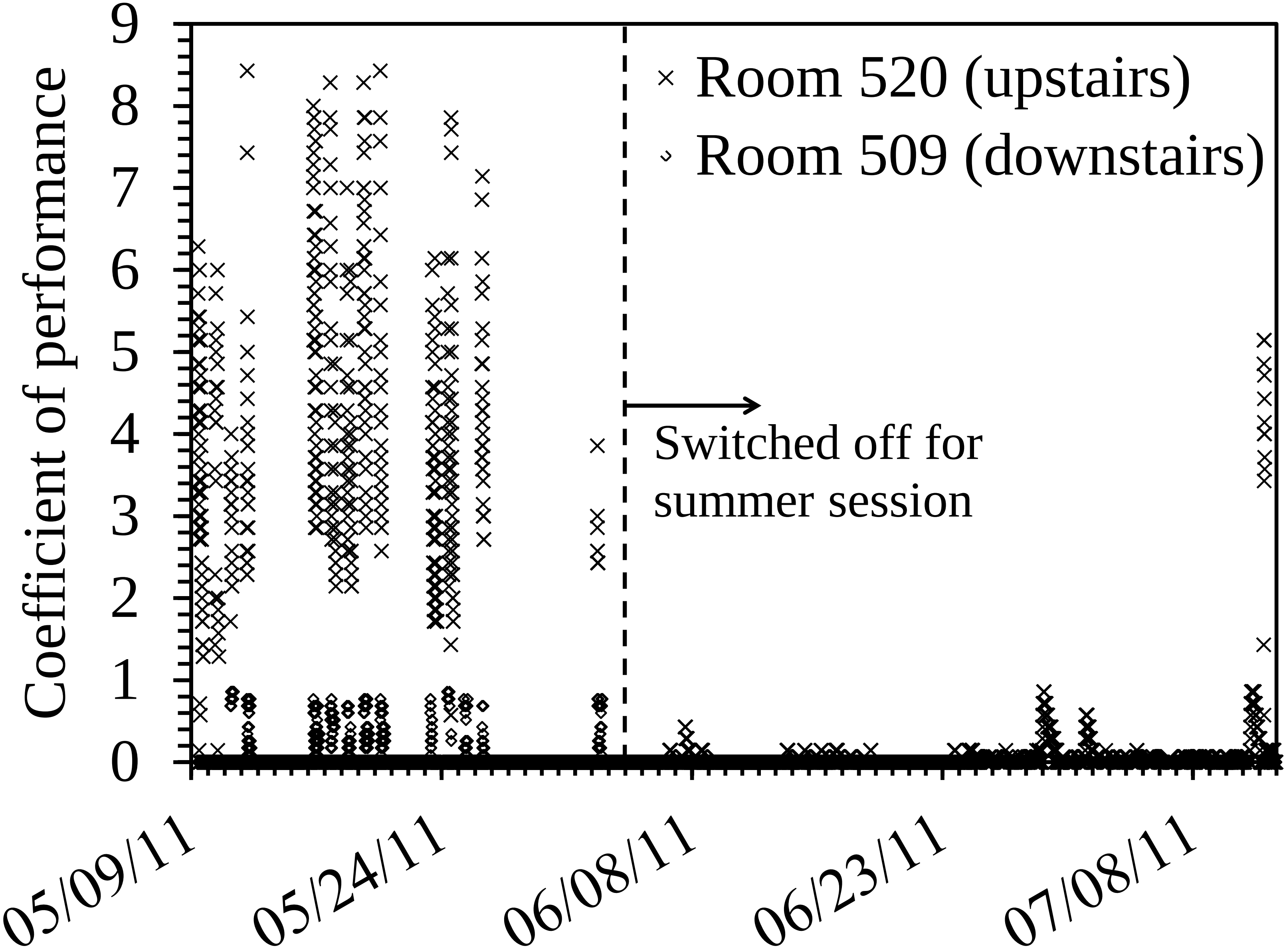
Temperature (°C)
45
40
35
30
25
20
15
10
5
0
Switched off for
summer session
Room 520 (upstairs)
Cooling mode
Exiting
Entering
05/09/11
05/24/11
06/08/11
06/23/11
07/08/11



Temperature (°C)
45
40
35
30
25
20
15
10
5
0
Room 509
(downstairs)
Heating mode
Switched off for
summer session
Exiting
Entering
05/09/11
05/24/11
06/08/11
06/23/11
07/08/11



Thermal energy delivered (kW)
60
50
40
30
20
10
0
Room 520 (upstairs)
Room 509 (downstairs)
Switched off for
summer session
05/09/11
05/24/11
06/08/11
06/23/11
07/08/11



Coefficient of performance
9
8
7
6
5
4
3
2
1
0
Room 520 (upstairs)
Room 509 (downstairs)
Switched off for
summer session
05/09/11
05/24/11
06/08/11
06/23/11
07/08/11

APPENDIX D: EXAMPLE GHP DATA COLLECTION DESCRIPTION

Monitoring Description

A preliminary monitoring program at Kinard Middle School, in Ft. Collins, CO was started in May 2011. Although the intention of this monitoring program was to monitor electricity consumption and entering/exiting water temperatures, the configuration of the commercial electricity system did not permit monitoring of electricity. However, the entering and exiting water temperatures were monitored successfully. As there are 73 heat pumps at Kinard, two heat pumps were selected for monitoring. These heat pumps share 98 boreholes having depths of 27.9 m and diameters of 12 cm. Each heat pump is designated to a single room, so a room on the upper floor (520) and a room below this on the lower floor (509) were selected.

The temperature was measured using ¼” type-T pipe plug thermocouples obtained from Omega Engineering. The temperature readings were monitored by USB dataloggers obtained from Lascar engineering. Pictures of the monitoring system at Kinard are shown in Figure 7.

Figure 7: Pictures of inlet/outlet monitoring system at Kinard

Calculation of Thermal Energy Delivered and Coefficient of Performance

The calculation of the thermal energy delivered is difficult, because the orange flow valves only circulate fluid through the heat exchange lines during periods of heating demand. Accordingly, the heat pump is not operating at all times. This is observed in the temperature time histories for the two rooms, shown in Figure 8. The results in this figure also indicate that the upper level room 520 was being cooled, while the lower level room 509 was being heated because it is on a lower floor and is more insulated from solar heating. This is an interesting aspect of a large commercial operation: each heat pump may have different heating/cooling goals to maintain a constant temperature in the room. The heat pumps were also shut off during the summer season, starting on June 7^{th}, 2011.

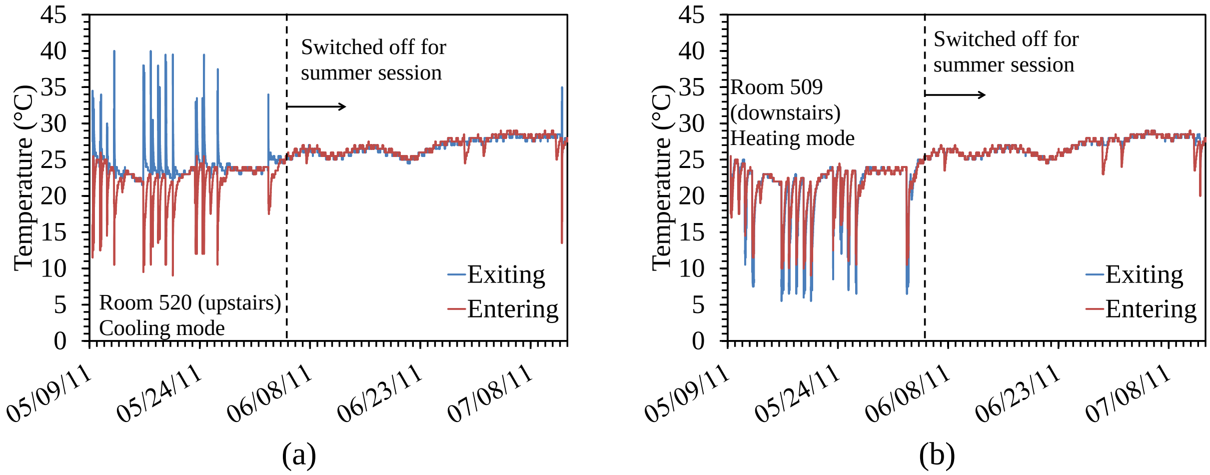


Figure 8: Temperature time histories for the two rooms: (a) 520; (b) 509

The difference in exiting and entering water temperatures can be used to calculate the thermal energy delivered, as follows:

$$\dot{Q} = \dot{m}\Delta T C_w$$

where $\dot{m}$ is the mass flow rate (equal to the circulation rate multiplied by the density of water), ΔT is the temperature difference between entering and exiting water temperatures, and C_w is the specific heat of water, equal to 4.186 kJ/(kg°C). The heat pumps for rooms 520 and 509 had different circulation rates of 26.5 and 20.8 liters/min, respectively. The thermal energy delivered is shown in Figure 9. These results indicate that the upstairs heat pump is delivering a significant amount of cooling thermal energy, while the downstairs heat pump is delivering a lower amount of heating energy.

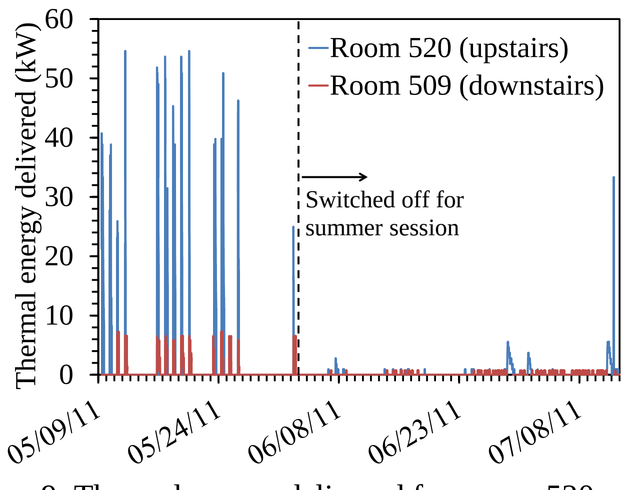


Figure 9: Thermal energy delivered for rooms 520 and 509

The electrical energy required to operate the heat pump in room 520 (Waterfurnace E-series model E035) in cooling mode is 6.48 kW for a 5 minute period, while the electrical energy required to operate the heat pump in room 509 (Waterfurnace E-series model E030) in heating mode is 8.5 kW for a 5 minute period. The coefficient of performance for the heat pumps can be calculated by dividing the thermal energy delivered by the electrical energy supplied. The coefficient of performance for the two heat pumps is shown in Figure 10. The coefficient of performance values for these heat pumps are slightly lower than reported by the manufacturer (approximately 10.5 for cooling mode and 3 for heating mode), but this may be due to their "incremental" use. In other words, because the heat pumps are only operated when they are needed, they do not establish their full efficiency in exchanging heat with the fluid in the ground loops.

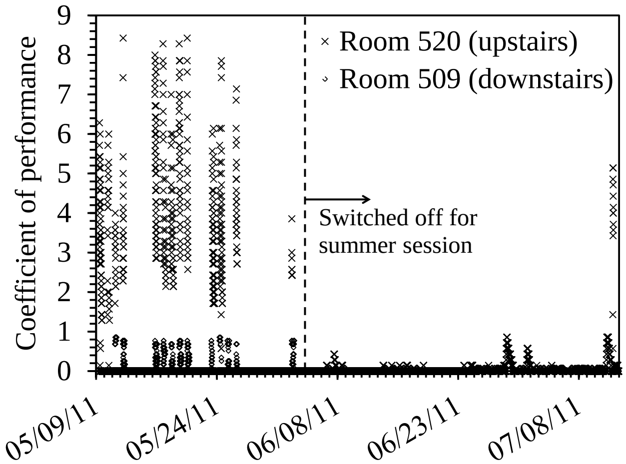


Figure 10: Coefficients of performance for the heat pumps in rooms 520 and 509

APPENDIX E: GHP WEB APPLICATION OVERVIEW AND TECHNICAL DESIGN

A. Web Application and Database Design: High-Level Overview

We recommend the construction of a web application that collects geothermal heat pump data from facilities managers and homeowners and makes that data available to researchers and policymakers. This section provides a high-level overview of the proposed design of the web application and its underlying database, including potential user scenarios, a preliminary software stack, a recommended development methodology and an estimated budget. This is an overview only – for more details please refer to the Technical design section below.

A1. User Scenarios

The proposed web application contemplates three primary types of users: facilities managers (public and commercial) or homeowners (residential), researchers, and data entry staff. The rest of this section defines each of these user classes and enumerates what we expect to be their key interactions with the application.

Facilities Managers and Homeowners

In the public and commercial building sectors, facilities managers typically supervise their buildings' electrical, plumbing, and HVAC systems and monitor overall energy usage. For buildings that rely on geothermal heat pump systems, facilities managers also ensure that the systems are functioning properly and decide when and how to use them. Therefore, they are often the individuals with the most knowledge about the heap pump installation. In the residential sector, the homeowner is primarily concerned with overall energy usage and associated costs. As such, the homeowner is the primary stakeholder from a residential perspective and is likely the person with the most knowledge of the heap pump system. Facilities managers and homeowners must be able to use the web application to provide critical technical and performance data and, in return, benefit from tools that will help them manage their systems.

Users will be able to perform the following data entry tasks:

- Register as a user, with a role as a facility manager or homeowner.
- Create, read, update and delete records for the building(s) for which they are responsible.
- Enter technical data for a GHP system, including geology and system design data, and performance data.

In exchange, once users have entered the relevant data, the web application will have enough information to:

- Perform simple payback and cost savings calculations for their GHP installations.
- Calculate greenhouse gas and other emissions savings for an installation.
- Compare their system peak load to the peak load of the utility system.
- Create and email links to surveys that collect data from building occupants about their experiences with the heating and cooling in the facility.

The goal of these sub-applications is to provide enough value to the user that he or she will expend the effort to enter GHP system information.

Researchers

Although facilities managers and homeowners will be the primary users of the web application, the purpose of the database is to provide meaningful data about GHP installations and subsequent performance to external researchers and policymakers. To support this goal, the project will provide three different ways for researchers to access collected data: via predetermined data downloads, via custom reporting, and (potentially) via integration with the National Geothermal Data System.

Predetermined data downloads. The system will provide "Show me the data!" style links to download large sections of the database in comma- and tab-delimited formats as well as in XML and JSON. Researchers will be able to load this data into their analysis or database systems and process it however they see fit. The web application may have to aggregate or scrub clean the data, depending on the privacy needs of the facilities managers and homeowners.

Custom reporting. Rather than provide extensively customizable reporting facilities directly in the web interface, we recommend allocating a certain amount of the maintenance software development budget to support interacting with researchers and programming custom queries over the collected data. This will meet the needs of interested researchers without building complicated pre-canned reporting that may or may not get used. The custom reporting will have to balance the privacy concerns of the homeowners and facilities managers with the data needs of the external researchers.

NGDS integration. The National Geothermal Database System (NGDS) is a nation-wide distributed database of geothermal data that consists of sub-databases contributed by federal and state agencies, universities, and third parties. We have discussed the possibility of integrating the GHP database with NGDS with Stephen Richard of the Arizona Geological Survey. This would entail providing the predetermined data downloads in a GIS format suitable for integration in NGDS.

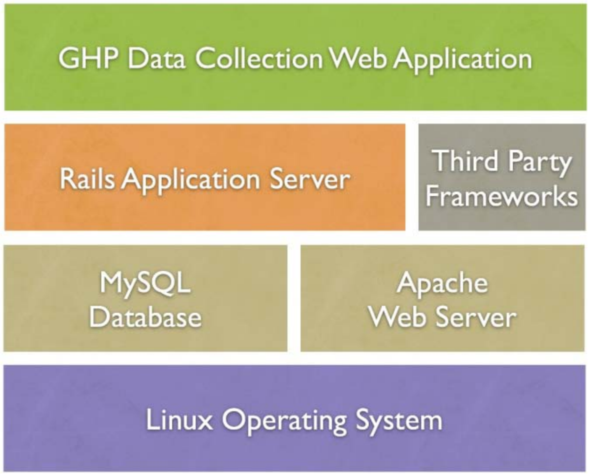
Data Entry Staff

Although facilities managers and homeowners would enter most of the data that the system collects, we recommend hiring interns or students to enter location-based utility information gathered from eGRID and perhaps geology data gathered from state agencies. This pre-seeding would make GHP data entry less onerous and encourage greater stakeholder participation.

A2. Software Stack

A web application's architecture can be thought of as a stack of loosely coupled components, each depending on services provided by the layers below it. Many software and application toolkits provide the services required at a given level of the stack; choosing between the options requires balancing price, complexity, ease of support, and performance. This section outlines the proposed software stack and the reasons for selecting each component. We are recommending that popular open source software be used, where possible, because it is low cost and because it has a large community available to troubleshoot problems. There are reasonable high-quality alternatives for many of the recommended components. Appendix Z lists these alternatives and examines their strengths and weaknesses.

Operating System



At the lowest level, we recommend using the *Linux* operating system because it is free, fast enough, very widely used, and because it provides a UNIX-like interface to the layers above it. Using Linux provides the most flexibility in choosing software at higher layers in the stack.

Web Server

The web server listens to incoming requests for web pages and either returns those pages directly (in the case of little-changing content) or delegates to a higher-level program that constructs pages dynamically. We recommend using the open source *Apache* web server because it is the most widely used web server and is sufficiently customizable to meet the system's needs.

Application Server

The application server responds to requests from the web server for dynamically generated content and is the level of the stack at which most of the GHP-specific logic resides. Application servers commonly decompose their tasks in terms of Views (pages that the user can see), Models (objects that communicate with the database to store and manipulate data), and Controllers, which mediate between Views and Models.

We recommend the open source *Ruby on Rails* application server because it is designed with developer productivity as its highest goal (rather than speed and scalability) and is customizable enough to support the needs. Rails uses the Ruby language, which is less well known than other languages (such as Java), but in our view the productivity benefits of Rails outweigh the risk of finding qualified programmers to work on it. Ruby on Rails is a rapidly evolving project that is still fairly new; however, it has quickly become one of the application servers judged best suited for medium-complexity web applications.

Third Party Frameworks

We recommend relying on a number of third party frameworks, both open source and commercial, to help implement the interactive portions of the web application. Chief among these will be *prototype.js*, an open source JavaScript library that makes it easier to dynamically validate entered data – this will be crucial for the GHP application because facilities managers and homeowners will be entering a large of amount of numeric data. We also recommend the use of the *Fusion Charts* framework, which displays charts and graphs using browser's Flash plugins, to display facility and utility load data.

Database

The database stores data in an organized fashion, executes complex queries over the data, and ensures integrity after a server crash or power failure. We recommend the use of *MySQL*, one of two widely used open source databases. Although it is not as full-featured as expensive commercial database products, MySQL is a good fit for a medium-sized web application database with low throughput needs.

A3. Development Methodology

Building software that end-users interact with directly is surprisingly difficult – typical first and even second tries at user interfaces are often severely lacking. The source of this difficulty is two-fold. First, developers tend to structure user interfaces around how the data is stored and analyzed, rather than how users think of it. Second, users, when asked, are often unable to articulate how they think about the task they would like to accomplish. It has therefore become increasingly common to involve users early on in the development process by providing rough but usable prototypes for evaluation and observing them as they attempt to accomplish desired tasks.

The key to creating a usable interface is to iterate through multiple design cycles to converge on a useful design, rather than precisely specifying the design upfront and then implementing it exactly. Iteration allows for flexibility and, since it forces the creation of usable systems early on, often allows potential design problems to be discovered, and corrected, early. This proposal assumes at least two iterations for every feature and for some (including the crucial data entry pages) it assumes at least four.

A4. Estimated Budget

Preliminary estimates for development of the GHP web application are based on the software stack recommendations, detailed above, and on utilizing an iterative design approach. Assumptions have been made about the number of iterations that may be required for each designed application feature. Based on these assumptions, it is estimated that a robust working prototype could be developed in the range of $250K-300K. The development of a fully-supported, production system would require additional investment for ongoing licensing, hosting, maintenance and technical support. Funding will also be required for user training and support staff.

The estimated timeframe for development of the prototype application is 9 months, assuming two (2) full-time developers, a Unix designer (for approximately 3 months), a project manager, and a representative user group. This estimate assumes no major changes in design.

B. Web Application Technical Design Details

This section describes the details of the recommended GHP web application, including the high-level tasks that users should be able to accomplish, the sub-application interfaces that will guide the users through those tasks, and the database tables that back the application. We also detail possible alternatives to the software stack recommended in Section A2 (above).

The design details are not set in stone, as they will likely change with feedback from users during the development process. However, they provide a solid starting point and good illustration of the proposed system design.

B1. User Stories

The *User Stories* design technique specifies the high-level interactions that users will have with a system. This technique focuses on what the user will be able to accomplish (rather than how the system will work) in chunks of functionality that are expected to take from a day to a week to implement. The goal is 1) to ensure that the needs of the user are expressed explicitly in the design and 2) to keep the stories small enough to make it possible to predict the resources required for completion.

The GHP Data Collection web application has three main types of users:

- *Facilities Managers* and *Homeowners* are responsible for the maintenance of GHP systems and for deciding when and how to use them. The main goal of the web application is to provide useful applications to these users to convince them to enter their system data.
- *Data Entry Staff* are support staff members (perhaps graduate students) who pre-seed the database with key information about electric utilities.
- *Researchers* are outside researchers who download the GHP system database for their own analysis.

The rest of this section lists the stories that each class of user will be able to perform.

Facilities Managers and Homeowners

Facilities managers and homeowners are able to create accounts and facilities, as well as enter technical, system design, geology, and performance evaluation data. Additionally, they can calculate the effects of the system on utility peak load, emissions, inhabitant comfort and cost. These users will be providing a large amount of information, so they must be able to begin entering data, leave the web application, and come back to continue where they left off.

User Accounts

- User should be able to create an account.
- User should be able to set their role as *homeowner* or *facilities manager*.
- User should be able to log in and log off.

Facility Identities

- User should be able to create a new facility record.
- User should be able to delete an existing facility record.
- User should be able to list their (possibly multiple) facility records.
- User should be able to enter location information for a facility.

System Design Data Entry

- User should be able to enter in basic the configuration of a facility's GHP system (Horizontal vs. Vertical, Open vs. Closed).
- User should be able to enter energy consumption characteristics for a facility.
- User should be able to enter the construction work requirement for a facility.
- User should be able to enter the details of the heat pump system design.
- User should be able to enter the capital cost of the components of the design.
- User should be able to enter the payback period (if known) of the design.

Site Data Entry

- User should be able to enter thermogeology data for a facility.
- User should be able to enter geology data for a facility for an arbitrary number of layers.
- User should be able to enter hydrology data (for an open loop system).
- User should be able to enter resource availability data.
- User should be able to enter building electrical and heating/cooling load data.

Performance Evaluation Data Entry

- User should be able to enter the monthly operating and maintenance costs of the system.
- User should be able to enter the monthly actual cost savings (if known) of the system.
- User should be able to enter time series data (monthly or yearly) about pump performance.

System Impact and Effect Applications

- User should be able to determine the GHP system's effect on peak electrical load.
- User should be able to determine the GHP system's effect on GHG emissions.
- User should be able to send out and collect e-mail surveys to determine the system's effect on building inhabitants.
- User should be able to calculate the cost savings from using the GHP system.
- User should be able to calculate the payback period for the GHP system.

Data Entry Staff

Data Entry Staff can create accounts, utilities, and enter eGRID and FERC information about utilities.

User Accounts

- User should be able to create an account.
- User should be able to log in and log off.

Utility Identities

- User should be able to create a new utility record.
- User should be able to delete an existing utility record.
- User should be able to list utility records they have created.
- User should be able to search for utility records.

Utility Records

- User should be able to enter and edit eGRID emissions information for a utility.
- User should be able to enter and edit FERC hourly electrical load information for a utility.

Researchers

Researchers can create accounts and download the database.

User Accounts

- User should be able to create an account.
- User should be able to log in and log off.

Data Access

- User should be able to download the installation database in XML, tab-delimited, and JSON formats.

B2. Sub-Applications

The GHP data collection web application consists of sub-applications of two types: 1) data entry applications, in which users enter data about themselves, GHP systems, or electric utilities and 2) impact analysis applications in which facilities and homeowners can gauge the effect of their GHP system. This section describes the details of how users enter information into sub-applications and how the sub-applications display their calculations.

Main Page

The main page is not an interactive application – its goal is to guide each class of users to the sub-applications they can use and provide an appropriate level of branding for the site.

Account Management

The account management application allows the user to register a new account, update the details of an existing account, reset a password, and delete an account. The account details include:

- First name, entered with a text field
- Last name, entered with a text field
- E-mail, entered with a text field
- User role entered with a popup menu containing the values “Facilities Manager or Homeowner”, “Researcher,” and “Data Entry Staff.”

My Facilities Application

The My Facilities application lists a facilities manager’s (or homeowner’s) facilities in a table. Each row in the table provides the name of the facility, a link to the Workflow application for that facility, an indication of how complete the entry is for the facility and a link to delete the facility. The table can be sorted by name or by completion. This application also includes a link to the Facility Creation application.

Facility Creation Application

The Facility Creation application allows the user to create a record for a new facility and give it a name. The application collects the following data points about a facility:

- The Name, Street Address, and City data points are entered with text fields.
- The State data point is entered with a popup menu populated with all state names.
- The Loop Type data point is entered with a popup menu containing the values “Open” and “Closed.”
- The Loop Configuration data point is entered with a popup menu containing the values “Horizontal” and “Vertical.”

Workflow Application

The geothermal heat pump data collection sub-applications collect a number of classes of data for each facility. Each class, once entered, allows enough information to drive a useful sub-application. The workflow application facilitates data entry by guiding the user through the collection of each class of data. It provides links to each currently available application and inactive links (greyed out) to applications whose dependencies haven’t been entered yet. Figure 11 shows the dependencies between applications: an arrow from one application to another means that the first must be completed before the second, e.g. the Account Management application must be completed before the Facility Entry application can be begun.

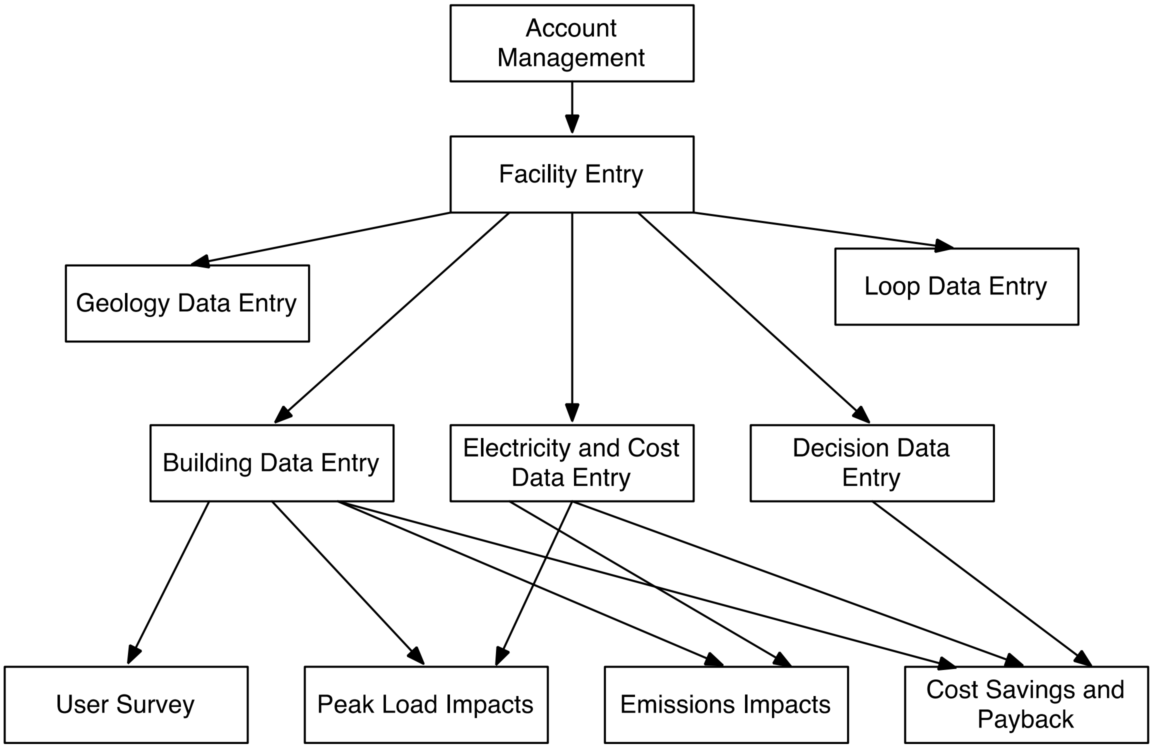


Figure 11: Application Dependencies

Geology Data Entry Application

The Geology Data Entry application allows the user to enter data points about the geological environment of the heat pump system. These data points are either about the entire site or about a specific layer of the geology. Each data point has an associated optional data collection method text area in which the user can enter how the data was collected.

Thermogeologic Setting. The thermogeologic setting data points are all site-specific:

- The Average Ground Temperature data point (in degrees Celsius) is entered with a text field validated to contain only numeric input.
- The Geothermal Gradient data point (in degrees Celsius/meter) is entered with a text field validated to contain only numeric input.
- The Frost Depth data point (in meters) is entered with a text field validated to contain only numeric input.
- The Groundwater Temperature data point (in degrees Celsius) is entered via a text field validated to contain only numeric input. This data point is only relevant for open loop configurations.
- The Depth to Groundwater data point (in meters) is entered with a text field validated to contain only numeric input.

Geology. The site-specific geology data points are:

- The Average Borehole Thermal Conductivity data point (in $W\ m^{-1}\ °C^{-1}$) is entered with a text field validated to contain only numeric input.
- The Average Borehole Thermal Diffusivity data point (in m^2/s) is entered with a text field validated to contain only numeric input.

- The Average Borehole Volumetric Heat Capacity data point (J/(m^3 °C) is entered with a text field validated to contain only numeric input.

Geology Layers. The user can create an arbitrary number of layers (and remove layers once created) with "Create" and "Remove" layer buttons. Each of these layers allows the entry of the following data points:

- The Soil/Rock Layer Thickness data point (in meters) is entered with a text field.
- The Soil/Rock Type and Soil/Rock Mineralization data points are entered with text fields.
- The Gravimetric Water Content data point (in percent) is entered with a text field.
- The Porosity and Hydraulic Conductivity or Permeability data points (in percent) are entered with a text field validated to contain values in the [0.0, 100.0] range.
- The Layer Thermal Conductivity data point (in W/(m °C)) is entered with a text field validated to contain only numeric values.
- The Layer Volumetric Heat Capacity data point (in unknown units) is entered with a text field validated to contain only numeric values.

Contingency Data Entry. The homeowner or facilities manager may not have all the geological data available. If this turns out to be a common case, then one option is for the web application to collect the facility's location and make a best guess about the geological data. Future iterations of the GHP web application could support this functionality by having support staff enter exogenous data such as climate conditions and geological setting at a relatively low geographical resolution. This would require additional support staff data entry applications.

Building Data Entry Application

The Building Data Entry application allows the user to enter data points about the building that the geothermal heat pump serves as well as the monthly heating and cooling load of the building and the high-level characteristics of the heat pump system itself. Each data point may be optionally associated with a text area describing how the data was collected.

Building Characteristics. The system collects the following building characteristics:

- The Building Type/Purpose data point is collected via a popup menu, with two choices: "Commercial" and "Residential."
- The Geographical Setting data point is collected via a popup menu, with two choices: "City" and "Rural."
- The Indoor Design Conditions data point is collected via two text fields, one for Temperature (in °C) and one for Humidity (in %), each validated to contain only numeric data.
- The Climate Setting, Energy Source, Complementary Heating System, and Complementary Cooling System data points are collected via a text area of descriptive text.

Building Heating/Cooling Load. The building heating and cooling load for each calendar month (in tons) can be entered in a table of text fields. Each text field is validated to be of numeric input only.

Heat Pump System. The system collects the following data points about the heat pump system:

- The Number of Heat Pumps data point is entered via a text field that is validated to be an integer value.
- The Heat Pump Manufacturer and the Heat Pump Model data points are entered via a text field.
- The Heat Pump Heating Size/Capacity and Heat Pump Cooling Size/Capacity data points (in tons) are entered via text fields validated to contain only numbers.
- The Manufacturer Heat Pump Efficiency data point is entered via a text field that is validated to contain values in the range [0.0, 1.0].
- The Manufacturer Heat Pump Efficiency Parameter is entered via a popup menu containing the values "COP" and "EER."
- The Heat Distribution System is entered via a popup menu containing the values "Local" and "Central."

Loop Data Entry Application

The Loop Entry application allows the user to enter data points about the loop component of the geothermal heat pump. Some data points are common to all loop configurations; others apply only to vertical or horizontal configurations. Fields should only be visible if they are relevant.

Common Data Points. The data points common to all configurations are:

- The Installation Type data point is entered with a popup menu allowing selection of "New System" and "Retrofit" values.
- The Designed Power Consumption data point (in kWatt units) is entered with a text field validated to contain only numeric input.
- The Designed Water Consumption data point (in liters/min units) is entered with a text field validated to contain only numeric input.
- The Type of Heat Source/Sink and Loop Type data points are entered with a text field.
- The Loop Length data point (in meters) is entered via a text field validated to contain only numeric input.
- The Loop Pipe Diameter data point (in millimeters) is entered via a text field validated to contain only numeric input.
- The Loop Pipe Material and Circulating Fluid Type data points are entered via a text field.
- The Designed Circulating Fluid Entry Temperature and Designed Circulating Fluid Exit Temperature data points (in °C) are entered via text fields validated to contain only numeric input.
- The Designed Fluid Flow Rate data point (in liters per minute) is entered via a text field validated to contain only numeric input.
- The Re-Injection Wells data point is entered via a popup menu containing the values "Yes" and "No."
- The Cut Depth data point (in meters) is entered via a text field validated to contain only numeric input.

***Horizontal Configuration Data Points*.** The data points relevant to only horizontal loop configurations are:

- The Number of Pipes in a Trench data point is entered via a text field validated to contain only integer input.
- The Trench Depth and Trench Width data points (in meters) are entered via a text field validated to contain only numeric input.

***Vertical Configuration Data Points*.** The data points relevant to only vertical loop configurations are:

- The Number of Boreholes data point is entered via a text field validated to contain only integer input.
- The Total Borehole Depth data point (in meters) is entered via a text field validated to contain only numeric input.
- The Borehole Diameter data point (in millimeters) is entered via a text field validated to contain only numeric input.
- The Grouting Materials data point is entered via a text field.

Decision Data Entry Application

The Decision Data Entry application allows the user to enter data points about the capital cost of the GHP system, its environmental impacts, and the resource availability at the site.

***Cost*.** The cost data points are:

- The Total Heat Pump Cost, Drilling/Trenching Cost, Design Cost, Piping System Cost, and Data Collection Cost data points (all in dollars) are entered with a text field validated to contain only numeric input.
- The Designed Payback Period data point (in years) is entered with a text field validated to contain only numeric input.

***Environment Impact Parameters*.** The environmental impact data points are:

- The Surface/Groundwater Temperature data point (in °C) is entered with a text field validated to contain only numeric input. This data point is only relevant to open loop configurations.
- The Aquifer Condition data point is entered with a text area and is only relevant to open loop configurations.
- The Surface/Groundwater Mineral Content data point is entered with a text field. This data point is only relevant to open loop configurations.

***Resource Availability*.** The resource availability data points are:

- The Surface Land Area data point (in m^2) is entered with a text field validated to contain only numeric input.
- The Groundwater Availability data point is entered with a popup menu containing the values "Yes" and "No."
- The Groundwater Unavailability Reason data point is entered with a text area. It is only relevant if the Groundwater Availability data point is "No."

Performance Data Entry Application

The Performance Data Entry application allows the user to enter information about how well the heat pump performs. Unlike most of the other data points in this database, these points are collectively associated with a particular date and the user may enter data for an arbitrarily large number of dates.

The data points are arranged in a table, sorted by date. There is a button to add a new row and each row has a button that deletes it.

Each row contains the following data points:

- The Date data point is entered via a date picker control.
- The Entering Heat Exchange Fluid Temperature, Exiting Heat Exchange Fluid Temperature, and Average Groundwater or Borehole Temperature data points (in °C) are entered with text fields validated to contain only numeric input.
- The Heat Exchanger Flow Rate and Groundwater Pumping Rate data points (in Liters/minute) are entered with text fields validated to contain only numeric input.
- The Coefficient of Performance data point (in percent) is entered with a text field validated to contain only numeric input.

Alternate Interface

Entering time series data is cumbersome, so the user may choose to upload a file containing the performance data in a Microsoft Excel xml or tab-delimited format. In this case, the server will parse the uploaded data and fill in the structure detailed above. The application does not support exporting the data back into the original format. Ideally, sensors attached to the GHP system would automatically generate the uploaded file. If this is found to be a common case, the application will parse whatever format the sensors use to report their data.

Electricity and Cost Data Application

The Electricity and Cost Data application is similar to the Performance Data application in that it records data about the installation over time and allows the user to enter data points for arbitrarily many dates. It differs from the Performance Data application in that the data points entered in this application represent time *periods*: either days, months, or years.

The data points are arranged in a table, sorted by date. There is a button to add a new row and each row has a button that deletes it. The application must validate to ensure that no entries have overlapping date ranges.

Each row contains the following data points:

- The Data Date data point is entered with a date picker.
- The Data Date Extent is entered with a popup menu containing the values “Day”, “Month”, and “Year.”
- The Actual Electricity Usage data point (in kWh) is entered with a text field validated to contain only numeric input.
- The Actual Electricity Peak Demand data point (in kW) is entered with a text field validated to contain only numeric input.
- The Complementary System Energy Usage data point (in kWh or m^3) is entered in a text field validated to contain only numeric input.
- The Complementary System Peak Demand Usage data point (in kW or m^3) is entered in a text field validated to contain only numeric input.

- The Operating Cost, Maintenance Cost, Historic Operating Cost, Historic Maintenance Cost, and Cost Savings data points (in dollars) are entered in text fields validated to contain only numeric inputs.

Alternate Interface
As in the Performance Data Entry Application user may choose to upload a file containing the performance data in a Microsoft Excel xml or tab-delimited format. In this case, the server will parse the uploaded data and fill in the structure detailed above. The application does not support exporting the data back into the original format. Again, if there is a common sensor apparatus that records this information, the web application will support whatever file format the sensors use to record their data.

Peak Load Impacts Application
The Peak Load Impacts application allows the user to enter the estimated hourly electrical load profile of their facility without the GHP system (i.e. the baseline load, wherein a different type of heating and cooling system is modeled) and the hourly load of their GHP system to determine the peak load impacts of their system based on the load profile of the utility.
The application collects the following data points:

- The Utility Name menu allows the user to select their electric utility from a popup menu prepopulated with relevant utilities. Once the user selects a utility, the application displays the load curve for the utility on a graph.
- The Baseline Facility Hourly Electrical Load data points (in kW), one for each hour of the day, are collected via a table of text fields, each validated to contain numeric data. As each data point is entered, it is displayed on the graph.
- The GHP Hourly Electrical Load data points (in kW), one for each hour of the day, are collected via a table of text fields, each validated to contain numeric data. As each data point is entered, it is displayed on the graph.

Alternate Data Entry Interface
The user may choose to upload the hourly load data points in Microsoft Excel or tab-delimited formats. In this case, the fields above will be populated with data parsed from the uploaded files.

Alternate Baseline Calculation Interface
In some cases, users may not have estimates of the baseline load available. If this turns out to be common, then future iterations may benefit from a more detailed Building Entry application that collects enough building data to estimate (via eQUEST or Manual J) the baseline load of the facility. The Emissions Impacts and Cost and Savings Applications could also use this same extended building data entry to remove the need for the user to directly enter baseline data. Section 5.1 provides the details of these baseline calculations.

Emissions Impacts Application
The Emissions Impacts application allows the user to view the greenhouse gas emissions saved by using the geothermal heat pump.
The user enters the following information:

- The Utility Name data point is selected from a popup menu populated from the pre-seeded utilities for the facility's geographic location.

- The Yearly GHP System Electricity Consumption (in kWh) is entered with a text field validated to contain only numeric data with a default value synthesized from what the user entered in the Electricity and Cost Data.
- The Estimated Baseline Yearly Electricity Consumption (in kWh) is entered with a text field validated to contain only numeric data.

As the user enters their data, the application dynamically calculates the estimated emissions impact (using the emissions rates that a data entry staff member has entered in the Utility Data Entry application) and displays it.

User Survey Application

The User Survey application allows the user to create a survey about building inhabitants' attitudes towards the heating and cooling in their buildings.

This application will allow the user to use a third-party survey tool (such as Survey Monkey) to construct a survey and send it to a specified list of e-mail inhabitants.

The key requirements of the third-party tool are:

- User should be able to create, update, and delete an arbitrary number of surveys.
- User should be able to specify both the questions and the possible range of answers for each question (whether multiple choice or text response).
- User should be able to create, read and update lists of survey recipients who will be sent by e-mail a link to a website to fill out the survey.
- User will be able to view the response to the survey, both graphically and in a tabular format.

This application may have to be custom-constructed if a suitable third-party survey tool cannot be purchased.

Cost Savings and Payback Application

The cost savings and payback application allows facilities managers and homeowners to explore the economic ramifications of their GHP system. The application is split into two tabs, one for cost savings and one for payback.

Cost Savings. The cost savings tab collects yearly costs for the estimated baseline system and for the actual GHP system and calculates the annual cost savings over those years.

The data points are collected and presented in tabular form, with each row collecting:

- The Year for which the row's data pertains, as a text field and validated to be an integer value as well as sorted and contiguous with surrounding rows' years.
- The Estimated Baseline Capital Cost, Estimated Baseline Maintenance Cost, and Estimated Baseline Operating Costs with text fields validated to contain only numeric input.
- The Actual GHP Capital Cost, Actual GHP Maintenance Cost, and actual GHP Operating Cost are collected similarly.

In addition to breaking out the yearly costs into categories, the user may choose (via a radio button) to enter combined yearly costs if only the combined sum is known.

The application presents the Cost Savings (over baseline) on a yearly basis in the final row of the table. These values are updated dynamically as the user adds and updates information.

Rather than enter the above data by hand, the user can upload an Excel spreadsheet (XLSX) or tab-delimited file; the web application will parse the upload and fill in the data above.

***Payback*.** The payback tab calculated the year in which a GHP system is expected to pay for itself. Unlike the Cost Savings tab, this tab collects average yearly data rather than specific values for each year in a series.

The system collects the following data points:

- The GHP Capital Cost is entered with a text field validated to contain only numeric input. This value is initially set to the combined capital cost that the user has entered in the Decision Data Entry application.
- The GHP Average Annual Operating and Maintenance Cost is entered with a text field validated to contain only numeric input. The value is initially set to the average of the combined operating and maintenance costs that the user has entered in the Electricity and Cost Data Entry application.
- The Baseline Capital Cost and Baseline Average Annual Operating and Maintenance Cost are entered with a text field validated to contain only numeric input.

The application calculates the payback period in years dynamically and updates it as the user enters or modifies data fields.

Utility Data Entry Application

The Utility Data Entry application is for use by data entry staff. It allows the user to create a record for an electric utility, enter an approximation of its service area, and provide electrical load data and eGRID emissions data.

To create a utility record, the user enters the following information:

- The Utility Name, in a text field.
- The Utility Potential Coverage Area, by checking at least one checkbox among boxes for all U.S. states in a possible service area.
- The CO_2 emissions (in kg/MWh) gathered from eGRID.
- The N_2O emissions (in kg/GWh) gathered from eGRID.
- The CH_4 emissions (in kg/GWh) gathered from eGRID.
- The hourly electrical load for the utility (gathered from FERC) as a table of text fields, one for each hour of the day, constrained to contain only numeric input.

B3. Database Tables

This section specifies the contents of the tables that store that data for the application.

Figure 12 shows the database tables and the relationships between them. A line between two tables indicates a “has-a” relationship; each line is annotated with the possible range of the count of that relationship. For example, every installation must have exactly one manager, but a manager can have an arbitrary number (including zero) of installations. When two entities can have multiple kinds of relationships with each other, the line is labeled with a name: e.g., a Building Data entry has both a cooling Monthly Load and a Heating Monthly Load.

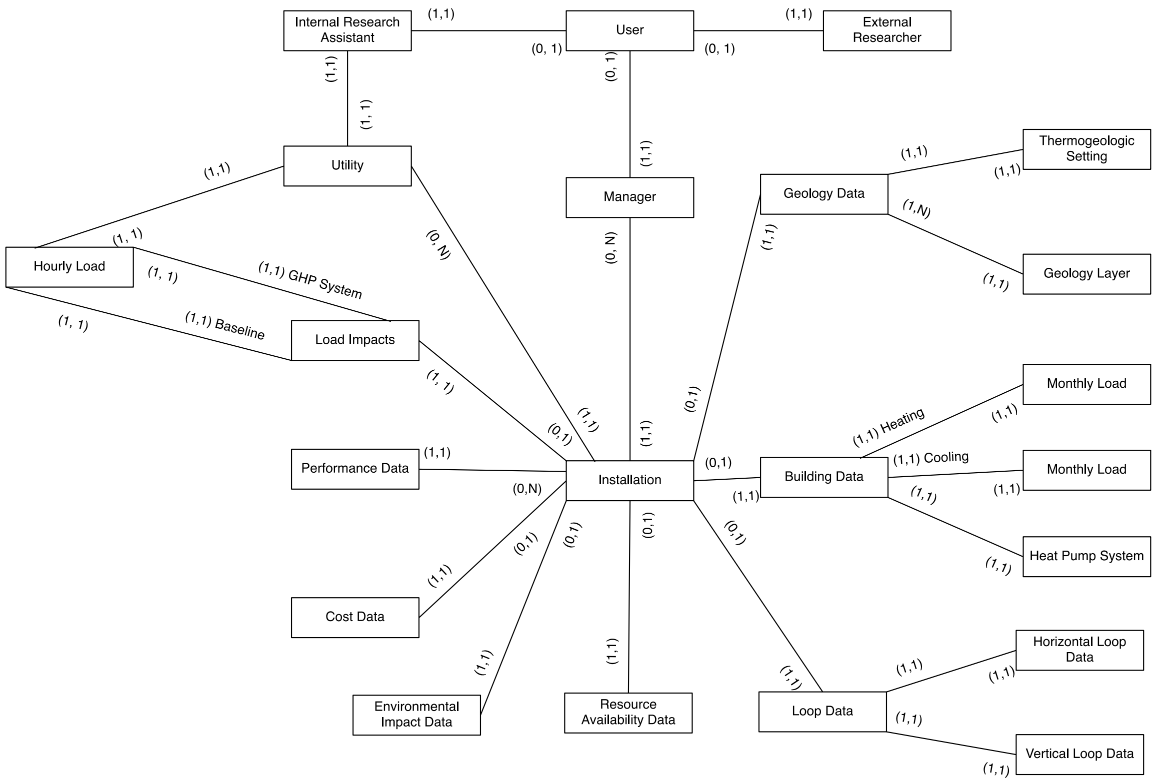


Figure 12: Database Entities

The rest of this section describes the database columns and their data types for the tables backing each entity. The data types can be:

- *strings*, i.e. text of arbitrary length
- *hashed strings*, which is text that has been run through a cryptographic hash function such as MD5.
- *integers*, i.e. natural numbers with some (unspecified) upper and lower bound.
- *sets*, in which the value stored is one of a set of values ({A, B, C}).
- *booleans*, which are either "true" or "false."
- *floats*, which represent numbers with decimal points, up to a certain, unspecified, precision
- *null*, which represents no value. Types are assumed to not allow null unless otherwise specified

Each table has an "id" column of type integer that acts as a *primary key* – that integer uniquely identifies the record in the table. Tables may have *foreign key* columns whose contents contain a value that is also the value of the id column in a row in another table: this specifies a relationship between a row in one table and a row in another.
Many columns have a corresponding column entitled column_name**_method**. This convention means that the data point is stored in column_name (in whatever data type is specified) and a textual description of how the datapoint was collected is stored in column_name_method.

User Table

The user table stores the name, email address, and password of a user and associates a user with their roles (manager/homeowner, data entry staff, researcher).

Column Name	**Data Type**
id	integer, primary key
first_name	string
last_name	string
email	string
password_hash	hashed string
manager_id	integer or null, foreign key in manager
data_entry_staff_id	integer or null, foreign key in data_entry_staff
researcher_id	integer or null, foreign key in researcher

Notes:

At least one of manager_id, data_entry_staff_id, and researcher_id must be non-null.

Manager Table

The manager table stores whether a manager is a homeowner or a facilities manager.

Column Name	**Data Type**
id	integer, primary key
manager_kind	{HOMEOWNER, FACILITIES_MANAGER}

Data Entry Staff Table

The data entry staff table records that a user performs the data entry staff role.

Column Name	**Data Type**
id	integer, primary key

Researcher Table

The research table records that a user performs the researcher role.

Column Name	**Data Type**
id	integer, primary key
instutition_name	string

Installation Table

The installation table ties an installation to a manager and records its name, address and the basics of its configuration.

Column Name	Data Type
id	integer, primary key
name	string
street_address	string
city	string
state	string restricted to postal abbreviations
loop_type	{OPEN, CLOSED}
loop_configuration	{HORIZONTAL, VERTICAL}
manager_id	integer, foreign key in manager

Geology Data Table

The geology data table records geology information for an installation. Each data point contains an associated description (with suffix "_method") describing how the data point was collected.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
average_borehole_thermal_conductivity	float
average_borehole_thermal_conductivity_method	string
average_borehole_thermal_diffusivity	float
average_borehole_thermal_diffusivity_method	string
average_borehole_volumetric_heat_capacity	float
average_borehole_volumetric_heat_capacity_method	string

Thermogeologic Setting Table

The thermogeologic setting table records thermogeology data for an installation.

Column Name	Data Type
id	integer, primary key
geology_data_id	integer, foreign key in geology_data
average_ground_temperature	float
average_ground_temperature_method	string
geothermal_gradient	float
geothermal_gradient_method	string
frost_depth	float
frost_depth_method	string
groundwater_temperature	float
groundwater_temperature_method	string
depth_to_groundwater	float
depth_to_groundwater_method	string

Geology Layer Setting Table

The geology layer table records data about a geology layer for a given site. Each site can have multiple layers.

Column Name	Data Type
id	integer, primary key
geology_data_id	integer, foreign key in geology_data
thickness	string
thickness_method	string
type	string
type_method	string
mineralization	string
mineralization_method	string
gravimetric_water_content	float
gravimetric_water_content_method	string
porosity	float (0.0 to 1.0)
porosity_method	string
hydraulic_conductivity_or_permeability	float (0.0 to 1.0)
hydraulic_conductivity_or_permeability_method	string
thermal_conductivity	float
thermal_conductivity_method	string
volumetric_heat_capacity	float
volumetric_heat_capacity_method	string

Building Data Table

The building data table records information about the building that the GHP system serves.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
building_type	{COMMERCIAL, RESIDENTIAL}
building_type_method	string
heading_load_id	integer, primary key in lmonthly_load
cooling_load_id	integer, primary key in monthly_load
geographical_setting	{CITY, RURAL}
geographical_setting_method	string
indoor_design_conditions_temperature	float
indoor_design_conditions_temperature_method	string
indoor_design_conditions_humidity	float
indoor_design_conditions_humidity_method	string
climate_conditions	string
climate_conditions_method	string
energy_source	string
energy_source_method	string
complementary_heating_system	string
complementary_heating_system_method	string
complementary_cooling_system	string
complementary_cooling_system_method	string

Heat Pump System Table

The heat pump system data table records information about the heap pump system for a building.

Column Name	Data Type
id	integer, primary key
building_id	integer, foreign key in buildings
heat_pump_number	integer
heat_pump_number_method	string
manufacturer	string
manufacturer_method	string
model	string
model_method	string
heating_capacity	float
heating_capacity_method	string
cooling_capacity	float
cooling_capacity_method	string
manufacturer_pump_efficiency_value	float
manufacturer_pump_efficiency_parameter	{COP, EER}
manufacturer_pump_efficiency_method	string
heat_distribution_system	{CENTRAL, LOCAL}
heat_distribution_system_method	string

Monthly Load Table

The monthly load table records information about the monthly heating or cooling load for a building.

Column Name	Data Type
id	integer, primary key
january_load	float
february_load	float
march_load	float
april_load	float
may_load	float
june_load	float
july_load	float
august_load	float
september_load	float
october_load	float
november_load	float
december_load	float

Loop Data Table

The loop data table records information about the loop used in the geothermal heap pump installation.

Column Name	**Data Type**
id	integer, primary key
installation_id	integer, foreign key in installations
installation_type	{NEW_SYSTEM, RETROFIT}
installation_type_method	string
designed_power_consumption	float
designed_power_consumption_method	string
designed_water_consumption	float
designed_water_consumption_method	string
sink_source_type	string
sink_source_type_method	string
loop_length	float
loop_length_method	string
loop_pipe_diameter	float
loop_pipe_diameter_method	string
loop_pipe_material	string
loop_pipe_material_method	string
circulating_fluid_type	string
circulating_fluid_type_method	string
designed_circulating_fluid_entry_temperature	float
designed_circulating_fluid_entry_temperature_method	string
designed_circulating_fluid_exit_temperature	float
designed_circulating_fluid_exit_temperature_method	string
designed_fluid_flow_rate	float
designed_fluid_flow_rate_method	string
reinjection_wells	boolean
reinjection_wells_method	string
cut_depth	float
cut_depth_method	string

Horizontal Loop Data Table

The horizontal loop data table records information about horizontal loop configurations.

Column Name	**Data Type**
id	integer, primary key
loop_id	integer, foreign key in loop_data
number_pipes_in_trench	integer
number_pipes_in_trench_method	string
trench_depth	float
trench_depth_method	string
trench_width	float
trench_width_method	string

Vertical Loop Data Table

The vertical loop data table records information about vertical loop configurations.

Column Name	Data Type
id	integer, primary key
loop_id	integer, foreign key in loop_data
borehole_number	integer
borehole_number_method	string
total_borehole_depth	float
total_borehole_depth_method	string
borehole_diameter	float
borehole_diameter_method	string
grouting_materials	string
grouting_materials_method	string

Resource Availability Data Table

The resource availability data table records information about resource availability design data.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
surface_land_area	float
surface_land_area_method	string
groundwater_available	boolean
groundwater_unavailability_reason	string
groundwater_unavailability_reason_method	string

Environmental Impact Data Table

The environmental impact data table records information about environment impact design data.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
surface_groundwater_temperature	float or null
surface_groundwater_temperature_method	string or null
aquifer_condition	string
aquifer_condition_method	string
surface_groundwater_mineral_content	string or null
surface_groundwater_mineral_content_method	string or null

Cost Data Table

The cost data table records information about the costs of installation components and payback period.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
heat_pump_cost	float
heat_pump_cost_method	string
drilling_trenching_cost	float
drilling_trenching_cost_method	string
design_cost	float
design_cost_method	string
piping_system_cost	float
piping_system_cost_method	string
data_collection_cost	float
data_collection_cost_method	string
payback_period	float
payback_period_method	string

Performance Data Table

The performance data table records information about how well the heat pump performed at a particular date.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
date_collected	date, unique for installation_id
heat_exchange_entering_fluid_temperature	float
heat_exchange_entering_fluid_temperature_method	string
heat_exchange_exiting_fluid_temperature	float
heat_exchange_exiting_fluid_temperature_method	string
heat_exchange_fluid_flow_rate	float
heat_exchange_fluid_flow_rate_method	string
coefficient_of_performance	float
coefficient_of_performance_method	string
ground_borehole_temperature	float
ground_borehole_temperature	float
ground_borehole_temperature_method	string
groundwater_pumping_rate	float
groundwater_pumping_rate_method	string

Electricity and Cost Data Table

The electricity and cost data table records information about the electricity usage and operating and historical operating costs of the facility over given extends (daily, monthly, and yearly).

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
data_date	date
date_extent	{DAY, MONTH, YEAR}
actual_electricity_usage	float
actual_electricity_usage_method	string
actual_electricity_peak_demand	float
actual_electricity_peak_demand_method	string
complementary_system_energy_usage	float
complementary_system_energy_usage_method	string
complementary_system_peak_demand	float
complementary_system_peak_demand_method	string
operating_cost	float
operating_cost_method	string
maintenance_cost	float
maintenance_cost_method	string
historic_operating_cost	float
historic_operating_cost_method	string
historic_maintenance_cost	float
historic_maintenance_cost_method	string
cost_savings	float
cost_savings_method	string

Hourly Load Table

The hourly load table records the hourly load over a day.

Column Name	Data Type
id	integer, primary key
load_00_hr	float
load_01_hr	float
load_02_hr	float
load_03_hr	float
load_04_hr	float
load_05_hr	float
load_06_hr	float
load_07_hr	float
load_08_hr	float
load_09_hr	float
load_10_hr	float
load_11_hr	float
load_12_hr	float
load_13_hr	float
load_14_hr	float
load_15_hr	float
load_16_hr	float
load_17_hr	float
load_18_hr	float
load_19_hr	float
load_20_hr	float
load_21_hr	float
load_22_hr	float
load_23_hr	float

Load Impacts Table

The load impacts table associates an installation with a baseline hourly load and a GHP hourly load. The hourly load table records the hourly load over a day.

Column Name	Data Type
id	integer, primary key
installation_id	integer, foreign key in installations
baseline_hourly_load_id	integer, foreign key in hourly_loads
ghp_hourly_load	integer, foreign key in hourly_loads

Utility Table

The utilities table contains information about a utility, its service area, and its hourly load.

Column Name	Data Type
id	integer, primary key
research_assistant_id	integer, foreign key in data entry staff table
name	string
service_states	string: comma separated list of state posta abbreviations
hourly_load_id	integer, foreign key in hourly load table
emissions_id	integer, foreign key in utility emissions table

Utility Emissions Table

The utilities table contains information about a utility, its service area, and its hourly load.

Column Name	Data Type
id	integer, primary key
carbon_dioxide_emissions	float
nitrous_oxide_emissions	float
methane_emissions	float

B4. Software Stack Alternatives

This section describes the benefits and drawbacks of possible alternatives to the software stack recommended in Section A2 (above).

Operating System

We recommend using the *Linux* operating system because it has become a de facto standard for web serving and therefore offers the most flexibility, but there are other possible operating systems. Microsoft *Windows* is a capable web serving OS, but its cost and lack of popularity in the server space make it less desirable except when Windows-specific features or applications are necessary. There are other UNIX-like operating systems, such as *FreeBSD* or Oracle's *Solaris* – but, again, the ubiquitous Linux is, in the general case, more preferable because of its widespread support.

Web Server

We recommend the *Apache* webserver because, like *Linux*, it is a de facto standard. However, if Windows is chosen for the operating system, then the Microsoft *IIS* web server may be a better choice because of its ease of configuration and management. *Nginx* is a possible alternative web server for Linux – it is not as well-known or well-supported as Apache, but it scales to larger websites.. However, since the projected traffic for the GHP Data Collection web application is relatively low, Nginx is not needed.

Application Server

We recommend the *Ruby on Rails* application server because it is designed with high developer productivity in mind, but there are viable alternatives. The *Django* application server is similar to Rails in many respects. Django uses the *Python* programming language, which is more popular than Ruby, so it may be easier to find developers for a Django project. Moving further along this axis, *PHP* is a very widely used web application programming language, and it is extremely easy to find PHP programmers. However, the language does not lend itself toward strong software engineering, so gains in the ease of finding programmers may be offset in programmer productivity.

Database

We recommend *MySQL* for the database because it is free, well supported, and feature-rich enough to support the application's needs. *PostgreSQL* is another open-source database that might be suitable – however, it does not offer as many options as MySQL. If Windows is chosen as the operating system, then Microsoft *SQLServer* is worth considering (although it is expensive) because of its ease of management. Other commercial SQL databases (such as *Oracle*) are too expensive and heavy-weight for this application, although their level of support is attractive. Finally, so-called "NoSQL" databases (which do not use SQL and are not "relational") are fast becoming popular for some classes of web applications. The *Cassandra* key-value database is a possibility in this space, however document-based databases, such as *CouchDB,* are probably not a particularly good fit.

APPENDIX F: SUMMARY OF REQUIREMENTS SUMMIT - Focus Center for Data Collection, Analysis, and Dissemination

OVERVIEW

The Geothermal Academy, pursuant to a grant from the United States Department of Energy's Geothermal Technologies Program, held a Requirements Summit for its Focus Center on Data Collection, Analysis, and Dissemination Project on April 15 and 16th, 2010 in Golden, CO at the Denver Marriott West hotel. This document records the attendance, activities, and findings of the Summit.

PURPOSE

This Summit invited experts and stakeholders from the geothermal heat pump (GHP) industry and its associations, GHP users and consumers, federal and state governmental agencies, non-governmental organizations, and academics to convene for the purpose of assisting the Geothermal Academy (GA) in designing a comprehensive data collection and analysis framework (DCAF) for actual (as opposed to modeled) GHP systems. The DCAF, when completed, will serve as a model for a potential nationwide information aggregation system for GHP systems, to be designed by the GA, a federal agency or lab, or another entity. Such a system would allow researchers to produce empirical, objective, statistically-valid data on the costs and benefits of GHP systems with respect to building-level economics, environmental impacts, and socio-economic performance.

AGENDA AND WORKING SESSION FORMAT

Day one (April 15th) provided the context for the summit, as expert speakers presented on an array of GHP-related topics and case studies of individual systems:

Day One Agenda – Thursday, April 15th

Agenda Item	Time	Presenter
Meet and Eat - Breakfast and Networking	8:00 – 8:50 AM	
Welcome and Opening Remarks	8:50 – 9:00 AM	Dr. Masami Nakagawa Geothermal Academy Director
GSHPs and Energy Security	9:00 – 9:20 AM	Kevin Doran Senior Fellow Center for Energy and Environmental Security, University of Colorado at Boulder
GSHP Lessons from Europe	9:20 – 9:40 AM	Tom Williams NREL Laboratory Program Manager – Geothermal Technologies
GSHP Technology	9:40 – 10:00 AM	John Lund Director of Geo-Heat Center Oregon Institute of Technology
Geothermal Academy: Focus Center for Data Collection, Analysis, & Dissemination - Project Overview and Summit Goals	10:00 – 10:45 AM	Adam Reed GA Project Technical Lead Center for Energy and Environmental Security University of Colorado at Boulder
MORNING BREAK	10:45 – 11:00 AM	

GEO and the Future: Organization, Standards, and a Platform for Growth	11:00 – 11:30 AM	Neil Chayet VP & Acting Executive Director of GEO (Geothermal Exchange Organization)
EPA's Energy Star Quality Installation Initiative for Ground Source Heat Pumps	11:30 AM – 12:00 PM	James Critchfield Director, Renewable Energy Technologies and Market Deployment at U.S. Environmental Protection Agency
LUNCH	12:00 – 1:15 PM	
NREL's GSHP Data Monitoring Project	1:15 – 1:45 PM	Erin Anderson Sr. Geothermal Analyst, NREL
Case Study 1 – Field Experience with Ground-Source Heat Pumps in Affordable Low Energy Housing	1:45 – 2:30 PM	Paul Bony Director of Residential Market Development ClimateMaster
AFTERNOON BREAK	2:30 – 2:45 PM	
Case Study 2 – Colorado Governor's Mansion and Capitol Building Retrofit Projects	2:45 PM – 3:45 PM	Lance Shepherd Manager, Design & Construction Programs Office of the State Architect
Case Study 3 – Kinard and Roberts School Comparison	3:45 – 4:30 PM	Stu Reeve Poudre School District Energy Manager
Day 1 Wrap-up & Day 2 Preview	4:30 – 5:00 PM	Adam Reed

Day two (April 16th) broke participants into three Working Sessions to determine a) what kind of metrics were optimal for evaluating a GHP system from a broad array of perspectives and b) what kinds of data were needed for such metrics and how to collect it. Each working session focused on one prong of a "triple bottom line" approach to analyzing a GHP system:

- Micro-economic session – This working session examined the cost-saving aspects of GHP systems, particularly from the point of view of an individual building owner or operator. It sought a methodology for determining how much money, over a given time horizon, a particular system has saved the owner/operator when compared to a conventional system. This included:
  1. An analysis methodology for building-operations-level cost savings;
  2. Cost-related data collection requirements for this methodology; and
  3. Means of collecting cost-related data (i.e., are there existing systems collecting such information, or is a new collection apparatus required?).

- Environmental session – This working session examined potential environmental benefits of GHP systems, from both the utility-system perspective and the individual building perspective. It sought a methodology for determining how many tons of CO2 equivalent emissions have not been emitted as a result of the owner/operator installing a particular GHP system over a conventional system. This included:
  1. An analysis methodology for both building-operations-level emissions savings and utility scale peak-load reduction impacts;
  2. Emissions-related data collection requirements for this methodology; and
  3. Means of collecting emissions-related data (*i.e.*, are there existing systems collecting such information, or is a new collection apparatus required?).

- Socio-economic session – This working session examined factors not captured in the micro-economic and environmental groups, and was less structured than other groups. It sought methodologies for, *e.g.*, determining how satisfied a GHP system's owner is with its space conditioning performance; or determining how the economic activity of installing and operating the GHP system affects the community in which it is located; or determining how the GHP system impacts the utility-system's peak load so as to reduce system-wide costs; or determining any other socio-economic measure that the group and moderator deemed relevant and appropriate. Regardless of the focus, this included:
  1. An analysis methodology for the selected focus;
  2. Data collection requirements for the methodology; and
  3. Means of collecting relevant data (*i.e.*, are there existing systems collecting such information, or is a new collection apparatus required?).

Following the Working Sessions, participants reconvened in an omnibus meeting to share outcomes and solicit feedback. This document and all Summit presentations are available on the Geothermal Academy website at www.geothermalacademy.org under the Meetings>April 15th-16th, 2010 path.

ATTENDEES

Name	Organization	Contact Information
• Erin Anderson	• National Renewable Energy Laboratory	• Erin.Anderson@NREL.gov
• Trey Austin	• Geo-Energy Services	• trey@geoenergyservices.com
• Renee Azerbegi	• Ambient Energy	• renee@ambient-e.com
• Barbara Betts	• Rico, CO	• barbara@telluridecolorado.net
• Andy Blackmun	• Habitat for Humanity Metro Denver	• Andy@habitatmetrodenver.org
• Paul Bony	• ClimateMaster	• paulsbony@yahoo.com
• Bruce Carpenter	• Habitat for Humanity Metro Denver	• Bruce@habitatmetrodenver.org
• Neil Chayet	• Geothermal Exchange Organization	• nchayet@chayetgroup.com
• Sam Crispin	• Colorado School of Mines	• sam.crispin@is.mines.edu
• James Critchfield	• Environmental Protection Agency	• Critchfield.James@epa.gov
• Kevin Doran	• Center for Energy & Environmental Security	• Kevin.Doran@colorado.edu
• Francisco Flores	• Colorado Governor's Energy Office	• francisco.flores@state.co.us
• Nancy Genova	• Colorado Mountain College	• ngenova@coloradomtn.edu
• Pete Jefferson	• ME Group	• pete.jefferson@megroup.com
• Mike Kaufman	• Ambient Energy	• Mike@ambient-e.com
• John Kelly	• Geothermal Exchange Organization	• jkelly@geoexchange.org
• Paul Leef	• University of Colorado at Boulder	• paul.leef@colorado.edu
• Jonah Levine	• Center for Energy & Environmental Security	• jonah.levine@colorado.edu
• Rebecca Levy	• Rico, CO	• ricolevys@gmail.com
• Dr. Xiaobing Liu	• Oak Ridge National Laboratory	• liux2@ornl.gov
• John Lund	• Geo-Heat Center, Oregon Institute of Technology	• John.Lund@oit.edu
• Jack Major	• Major Geothermal	• Jack@majorgeothermal.com
• Scott Martin	• RMH Group	• smartin@rmhgroup.com
• Richard Mignogna	• Colorado Public Utilities Commission	• Richard.Mignogna@dora.state.co.us
• Ben Northcutt	• Colorado GEO Energy Association	• ben@gogeonow.org
• Joel Poppert	• Alpine Drilling	• joel@alpinegeothermal.com
• Tom Potter	• Southwest Energy Efficiency Project	• tpotter@allamericanenergy.com
• Terry Proffer	• Major Geothermal	• loopman@majorgeothermal.com
• Stu Reeve	• Poudre School District	• stur@psdschools.org

• Gunter Ritter • Jenni Schaefer • Phil Schoen • Lance Shepherd • Creig Veldhuizen • Craig Watts • Tom Williams	• Golden Sustainability Advisory Board • Habitat for Humanity Metro Denver • Geo-Enterprises • Colorado Office of the State Architect • CFA Terra Causa Capital • MKK Consulting Engineers • National Renewable Energy Laboratory	• gritter@brwncald.com • Jenni@habitatmetrodenver.org • pschoen@geo-enterprises.com • Lance.Shepherd@state.co.us • creigv@terracausacapital.com • cwatts@mkkeng.com • Tom.Williams@nrel.gov

FINDINGS

Micro-economic Working Session

Participants:
Tom Williams – NREL, Facilitator
Jack Major – Major Geothermal
Gunter Ritter – City of Golden Sustainability Advisory Board
Dr. Xiaobing Liu – Oak Ridge National Laboratory (ORNL)
Andy Blackman – Habitat for Humanity Metro Denver
Joel Poppert – Alpine Drilling
Craig Watts – MKK consulting engineers
Terry Proffer – Major Geothermal
Peter Jefferson – ME Group
Creig Veldhuizen – Terra Causa Capital
Tom Potter – Southwest Energy Efficiency Project (SWEEP)
Phil Schoen – Geo-Enterprises
Sam Crispin – Colorado School of Mines Facilities Management

The micro-economic working session determined the following to be desirable attributes of a methodology for determining economic benefits:

- Simple
- Directed toward an audience of policymakers and/or building and home owners
- Universally accepted and understood
- Engages the user (perhaps through incentives)
- Scalable
- Defines clear benefits
- Geothermal specific
- Fair (in the comparison)
- Foolproof data collection
- Covers full life-cycle
- Full disclosure: detailed, supported by documentation, and transparent
- Global in scope
- Independently confirmed data
- Widely available dissemination of data to the public and industry
- Includes maintenance data and implicit costs to reach measures of true cost
- Includes analysis already done
- Provides guidelines for industry use

The group determined that their methodology for comparison with a conventional system must cover the following topics:

- Time horizon
- Comparison system definition
- What is likely to resonate with users of different classes (residential, commercial, industrial?)
- What are the first big components that must be replaced in various systems?
- Building life and building ownership life
- Finance life / Payback period
- Obsolescence (what is the life of the system before it becomes outdated?)

Building Life

The group found it important to consider building life from the perspective of the building investor. Investors will consider the lease rates that the building may command and their own exit strategy in determining the hold period and the desired return on investment. Residential buildings tend to have a building life of 5-7 years. Commercial buildings have longer building lives. The feasibility of installing a system will vary according to the decision-maker's building life estimate. It was recognized that the identity of the decision-maker within an organization is likely to vary. Therefore, cost-related data for a GHP system should be collected over the life of the building from the investor or owner's perspective, not from an absolute "bricks and mortar" life of the building. The group suggested that the DCAF make the building life for a structure variable according to the individual customer, to allow him to analyze performance based on his particular needs. The group raised the question of whether to separate building life from the lives of the loopfield and GHP system, but did not come to a consensus answer.

Comparison Systems

A number of different systems might serve as the comparison or "counterfactual" system for the GHP system being measured: wood burning stoves (rural areas), natural gas furnaces (Western US), propane or heating oil (Northeastern US), and electric furnaces and cooling systems, as well as emerging technologies and other renewable energy systems. The residential market provides the simplest opportunities for such comparisons, while the commercial market is much more complex. Regardless of the counterfactual system type, all comparisons come down to measures of energy cost. The group came up with a variety of approaches to make for fair energy cost comparisons:

- ASHRAE standards 90.1, 189, and 90.2 – all commercial building requirements – were mentioned as one such avenue. Such a method would presume that the counterfactual system met the appropriate ASHRAE standard, and then model costs from that point onward.
- The inclusion of carbon dioxide pricing into the energy cost equation could also be significant, and it was suggested that comparisons to conventional systems include a "what if" analysis of system cost differentials at various carbon prices.
- Retrofit markets should be distinguished from new building markets, as the two may produce very different results.
- Market analyses should be region-specific to account for climatic conditions as well as fuel costs.

- For the GHP system, which will be monitored empirically, it will be necessary to isolate its energy demands from the other energy requirements of the building. This should be equivalent to the heat requirements of the building.

A number of structural barriers make fair and accurate comparisons to counterfactual systems challenging. The group cited a need for new industry standards and codes to demand tighter mandates for new buildings when compared against old systems, so as to improve efficiency over time at a continuous rate, as is done in the German market. Such an approach would require that any new system installed would have to meet or beat the old system's standards with a lower cost of operation. This will only achieve so much in the US though, because the US has low compliance rates with existing codes when compared to Europe. Moreover, US codes and standards lack long term planning or uniformity, and tend to vary with political administrations. The implementation and enforcement of uniform, long-term standards would help to combat the demands of developers for "value engineering" – a term that refers to lowering up-front costs by skipping important analytical steps, shifting the costs of a poorly-designed system onto the building operator, who must then pay higher energy bills.

The group found that knowledge of up-front costs for both the GHP system and the counterfactual system was critical. Globally-speaking, such data could be aggregated into cost estimates for GHP systems on a square foot basis.

Metrics

Simple operation cost (kWh/m^2) was identified as insufficient for a full understanding of GHP cost benefits. The group suggested utility capacity factors and load demand as important factors, perhaps thinking of how future shifts to dynamic and time of use pricing schemes might affect the cost of operation of different systems. Additional metrics included thermal comfort, acoustical quality, and air quality – all categories where GHP systems have a reputation for superior performance.

Data Collection

The group noted a wide variety of needed data types and collection methodologies:

- Submetering for the actual power consumed
- Plotting performance against the local climate profile
- Measuring utility peak loads for the service territory
- Improved monitoring of building energy flow
- Collect data from customers as a sales strategy – consumer pays for monitoring equipment, which allows the installer to determine when the system is operating suboptimally and needs modification.
- Soil thermal conductivity needs to be measured below ground. Having a lot of such data would be beneficial for designers.
- Data could be linked to utility rate benefits *vis a vis* avoided peak loads, providing another incentive for building owners to install monitoring equipment.
- System efficiency over time, as ground temperatures may shift.
- Operation and maintenance costs

- System installed costs, especially in the commercial market, including valid comparisons of mechanical systems
- Detailed installation costs – drilling, breakdown costs, horizontal vs. vertical loops, excavation, net cost of loop by category.
- Geographic implications – can be collected from top construction markets in US
- Climate change implications for solar, wind, water, and temperature.
- Thermal capacitance of ground
- Variability of thermal conductivity in the region, perhaps a database of Tc's
- Quality of backfill (has high variability)
- Installations within a geographic area.
- Oil & Gas industry well-log data has a lot of information on shallow ground conditions, including electric logs, resistivity logs (goes public after 3-5 years). Need for regional or national database of such information.
- Software is needed to track commercial and residential energy use.
- Building heating and cooling capacity – heat extraction vs. heat rejected.
- Data monitoring systems and data loggers (e.g., advanced metering and other smart home networks may provide a path forward).
- Manufacturer-installed data collection points on geoexchange units are cheap and easy plug-n-play technology.
- Blind sample datasets for specific regions are collected by rural electric cooperatives allow for statistical sampling of energy use per square foot.
- Commercial buildings, particularly schools, often have Direct Digital Controls (DDC) systems.

Environmental Working Session

Participants:
Jonah Levine – CEES, Facilitator
James Critchfield – US EPA
Erin Anderson – NREL
Ben Northcutt – Colorado GEO Energy Association
Mike Kaufman – Ambient Energy
Rebecca Levy – Town of Rico
John Lund – Oregon Institute of Technology
John Kelly – Geothermal Exchange Organization

Due to the broad scope of potential environmental effects related to GHP systems, the environmental working session first identified a running list of impacts that might be monitored:

- CO_2 emissions
- Ground temperature changes
- Water
  - Temperature
  - Chemistry
  - Flow
- Air quality

- NOx
- SOx
- Hg
- Particulate

- Land use
  - Construction
  - Drilling
  - Increase/decrease
- Life Cycle Assessment
- Refrigerants
- Decommissioning /landfill
- Consumer behavior
- Energy/Power

The group highlighted in green are the impacts that should be measured in the near term, with the understanding that the DCAF could incorporate other impacts in future years if desired. Consequently, methodologies and data collection needs and strategies were focused on the near-term goal of determination of carbon dioxide equivalent (CO2e) emissions, ground temperatures, and energy/power consumption. Energy/power consumption and CO2e emissions are both aspects of "run time" environmental impacts of the GHP system. Ground temperature changes due to operation of a GHP system may reduce the efficiency of the system over time as the average ground temperature increases or decreases from year to year, and thus have longer-term effects on both energy/power consumption and CO2e emissions.

Energy/Power Consumption

The group developed a matrix that would list the efficiency, energy input, and energy output of both the GHP and relevant other technologies that might serve as counterfactuals:

System	Efficiency	Energy Inputs	Energy Outputs
GHP			
NG/ AC			
ASHP			
Oil/AC			
Electric			

In this matrix, energy inputs include electricity or fuel needed to run the equipment. For the GHP system, this includes the electricity (kWh) needed to run the following components:

- Field pump/well pump
- Compressor
- Fan
- Distribution
- D super heater.

Energy output, measured in kWt, refers to the heating energy provided by the GHP system or any of the counterfactuals. The efficiency of the device is determined by dividing the energy output by the energy input of a particular device. The matrix would allow the DCAF to compare the energy used by the GHP system with the energy that would be used by a comparable natural gas/AC, air-source heat pump, heating oil/AC, or fully electric counterfactual system. The counterfactual systems would in most cases require modeling based on the building in question. The GHP system could be either directly measured or modeled.

CO2 equivalent emissions

Once the energy/power metrics of the GHP system are established and compared to counterfactual systems, the GHG emissions or emissions savings attributable to the GHP system can be determined. Two factors affecting CO2e emissions were identified:

- Peak load impacts of the system, and
- The emissions factor of the regional power system providing electricity to the GHP system.

The group recognized the importance of peak load impacts for GHP systems, as they are reputed to reduce peak demand for the electrical utility. The group was however unable to reach a consensus on how to calculate such peak impacts.

Emission factors for regional power systems are on file with the US Environmental Protection Agency (EPA), and are available through the eGRID application.[1] An emission factor measures the amount of CO2e emissions (in lbs) that result, on average, from generating 1kWh of electricity in a given region. By multiplying the energy input of the GHP system by the emission factor for the regional electricity grid, one can determine the CO2e attributable to the GHP system. The same can be done for counterfactual systems, though systems utilizing natural gas and oil would require further non-grid emission calculations. Note that this method does not take into account emissions savings from peak-load reductions attributable to the GHP system.

Ground Temperature and Ground Temperature Impacts

Ground temperature impacts may be determined by measurements over time of:

- Supply water temperature (°F) and flow (gal/min)
- Loop Return water temperature (°F) and flow (gal/min)

The group also suggested measurements of interior set point temperatures over time, though it was unclear from the record why this was suggested.

Data Collection

Data collection could be achieved through installation of specific sensors or meters on each system, or through existing meters from which data might be derived. The group suggested advanced metering infrastructure (AMI, also called "smart meters") now being deployed by many utilities as a means of collecting data. Other options include sensors installed by the GHP installer at the request of the user for monitoring and later improvement of the system. Sensor installations could be tied to local, state, or utility rebates to encourage users to opt in. Other options mentioned included consumer participation – where the consumer would self-report such

[1] http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_GHGOutputRates.pdf

information – and government participation – where sensors and monitoring equipment would be installed and paid for by a government agency.

Socioeconomic Working Session

Participants:
Kevin Doran – CEES, facilitator
Lance Shepard – Colorado Office of the State Architect
Jenni Schaefer – Habitat for Humanity Metro Denver
Nancy Genova – Colorado Mountain College
Barbara Betts – Town of Rico, CO
Paul Bony – ClimateMaster
Paul Leef – University of Colorado at Boulder
Richard Mignogna – Colorado Public Utilities Commission

The socio-economic group tackled a number of data collection efforts that did not fit under the micro-economic or environmental analysis prongs: customer satisfaction, GHP installation as a local economic driver, and GHP impact on utility system peak load. The group also had a significant discussion of public educational and outreach needs with respect to GHPs, but we have omitted notes from that discussion in this document because it is outside the narrow scope of DCAF data collection requirements.

Customer Satisfaction
The group identified six criteria likely to affect customer satisfaction:

- Comfort – heating, cooling, humidity levels, air quality, noise, control
- Cost – installed, O & M, etc.
- Reliability
- Resale value
- Carbon footprint, environmental considerations *vis a vis* image and peer signaling
- Aesthetics
- Value added

Note that unlike actual calculations of cost and environmental impact covered by other working sessions, these criteria are to be measured with respect to user perceptions and levels of satisfaction, not objective figures. The group found it important that such individual satisfaction data be overlaid with information regarding demographics, geography, and regulatory landscape (particularly with respect to buildings) in each area.

The customer satisfaction methodology should measure:

- type of customer (income level, demographics, profession, etc.)
- type of installation (residential (new/old)(multifamily vs single family), large commercial, industrial (warehouse, mfg.), small commercial, institutional (hospital, school, admin bldg.), district, large facilities (special event venues)

- customer expectations (before installation) and impressions (after installation) regarding comfort, cost, reliability, resale value, carbon footprint and environmental considerations, aesthetics, and value added using standardized metrics
- ancillary systems (PV, wind turbine, etc.).

Information could be collected through focus groups for particular kinds of facilities, as well as from customer surveys. Pre-installation surveys will be easier to collect, because they can be done while the installer is at the location. Post-installation surveys will prove more problematic. Due to low response rates on such surveys, it may be necessary to provide customers with an incentive to complete them. The survey could also be integrated into a certification process that provides the customer with additional benefits. The group noted that length of surveys is a factor in the likelihood of completion, as is the method of survey (telephone, e-mail, snail mail).

GHP Installation as a Local Economic Driver

The installation of GHP systems can create work for designers, drillers, and installers, many of whom may be local workers. Roughly 1/3 of the average $20,000 GHP installation leaves the immediate vicinity of the project to pay for equipment, parts, and materials. The U.S. Green Building Council's LEED program has tools for calculating local materials use in a project. Local government entities can encourage installation of GHP systems though incentive and rebate programs. Finally, installation of GHP systems can have beneficial effects on peak loads, reducing the need for utilities to invest in and utilize expensive peak generating resources. Money that would have been spent on peak generation can be used elsewhere in the local economy, where it may produce more jobs or higher socio-economic value.

GHP projects may improve job creation figures and reduce upfront costs by scaling to multiple-dwelling or large-building-sized projects. Habitat for Humanity achieved this at its Hope Crossing community in Oklahoma. Large corporate retailers may find corporate goodwill as well as long-term cost savings in installing GHP systems using local labor and materials.

Job and Economic Development Impact (JEDI) models employed by the US Department of Energy will be useful for calculating local economic benefits from GHP installation projects. Additionally, the lower energy costs to the end user provided by the GHP system free up funds for more and better-paying jobs. The group noted the example of a school district having more money to hire better teachers because it has cut its energy bills through the GHP system.

GHP Impact on Utility System Peak Load

GHP systems can provide reductions in utility peak loads when compared to some other systems. The choice of the counterfactual system or baseline is critical in this determination. The group noted that the baseline could be the system replaced by the GHP system, or a non-GHP system in a similar facility in the same location. Data from the Energy Information Administration (EIA) could also be used to set a normalized baseline for comparison.

Collection of data for determining peak load impacts is also challenging. The group noted a number of potential methods:

- Advanced metering infrastructure (smart grid) – feeds information directly to the utility regarding time of use.
- Some utilities (such as the Delta Montrose Electric Association) keep data sets of peak usage information for their service territories.
- Dedicated monitoring equipment for peak-time energy usage.
- Aggregation of multiple GHP systems in a service territory may show the benefit more convincingly and at greater scale. The Hope Crossing project could be used for this, for example. Such aggregations could be scaled up to larger types of structures using modeling such as EQUEST.

NEXT STEPS

This document represents our best attempt at a distillation of outcomes and findings from the Requirements Summit. Our next steps in the Focus Center project are as follows:

1. Seek feedback on this document from Summit Participants – **please use "track changes" in Word and send us additions or clarifications to this document as soon as is convenient for you**. We want the most accurate portrayal of Summit outcomes that we can get.
2. The GA team, in consultation with the GA Steering Committee, will make executive decisions regarding which analytical methodologies and data collection requirements from the Summit should be incorporated into the DCAF. By the end of July, the GA team will create a Version 1 Requirements Document detailing the kind of data that needs to be collected from GHP systems for the DCAF.
3. The GA team will also create a Design Document detailing how the collected data is to be organized and utilized for the production of policy-level metrics within the triple bottom-line framework. We aim to have the Version 1 Design Document completed by the end of September.
4. Activities 2 and 3 will occur simultaneously with testing of data collection and analysis activities on actual GHP installations.